Harvard-MIT Division of Health Sciences and Technology
HST.535: Principles and Practice of Tissue Engineering
Instructor: Yongnian Yan

MIT-TH

Scaffold Manufacturing of Tissue Eng. Using Free Forming Fabrication

Prof. Yongnian Yan

2003.9.10

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What's FFF ?

Free Forming Fabrication

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Definition

FFF —— The General name of

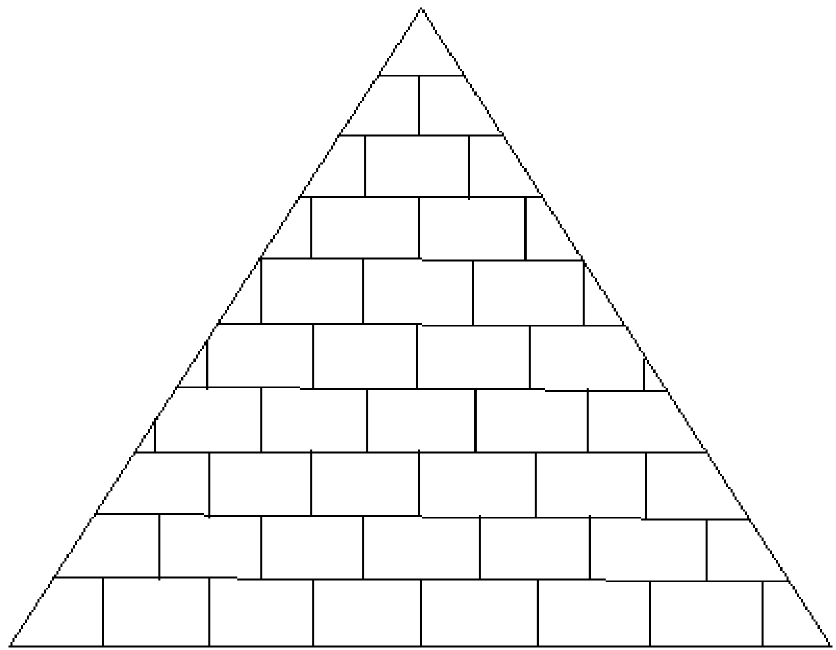
Making Any Complex

Structure using Assembling

Elements

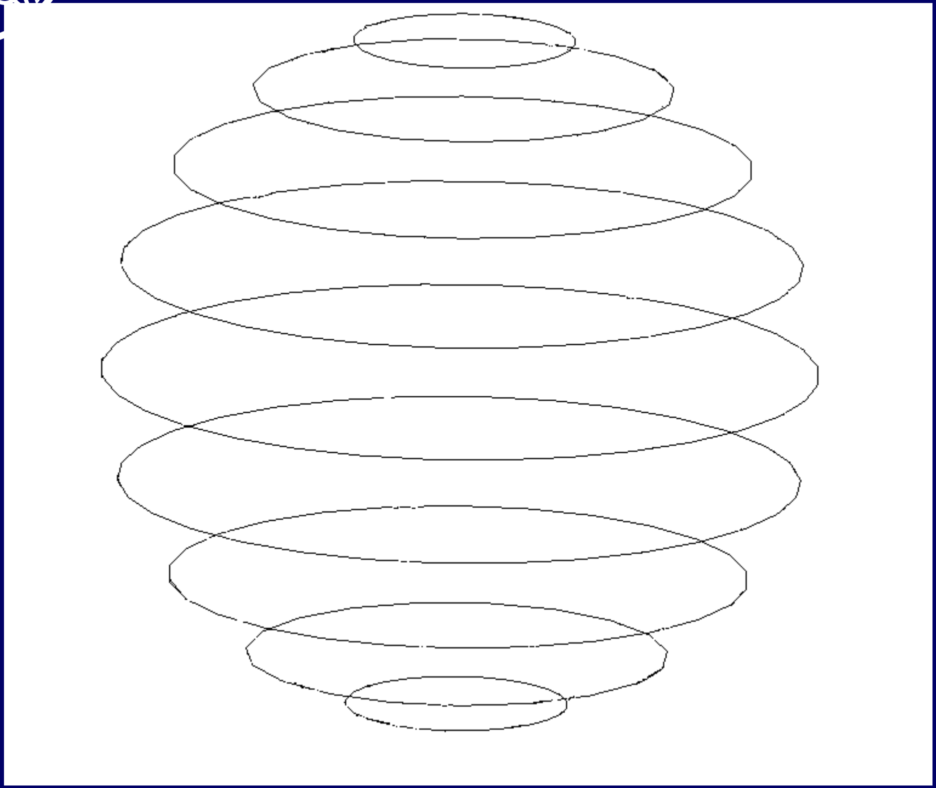
Driven Directly by CAD Model

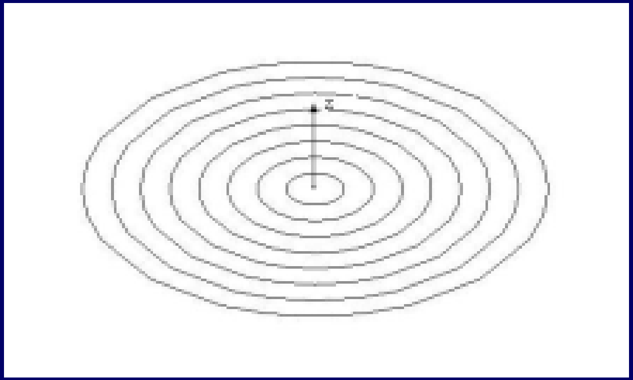
Pyramid

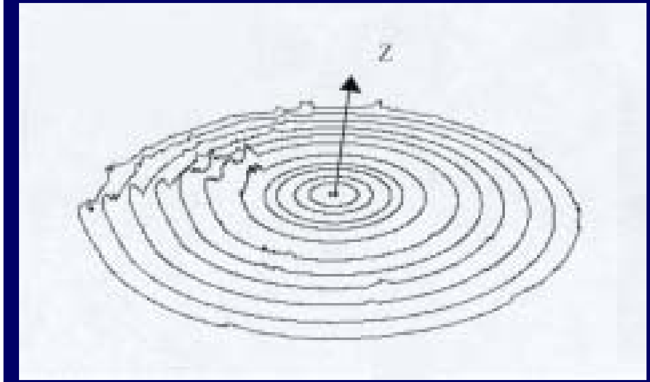


- **First: Shape the stones into standard types**
- **Then: Pile the stones up**

The globe







- **Slice the globe along the latitude, the cross section will be circular rings or concentric rings**

3D-Globe Model

Design and Building Process

- ***Design***
  - The number of stones
  - The order of piling

------- ***Discretization***

(Decomposing)

- ***Building***
  - Pile pyramid by stone elements

------- ***Accumulation***

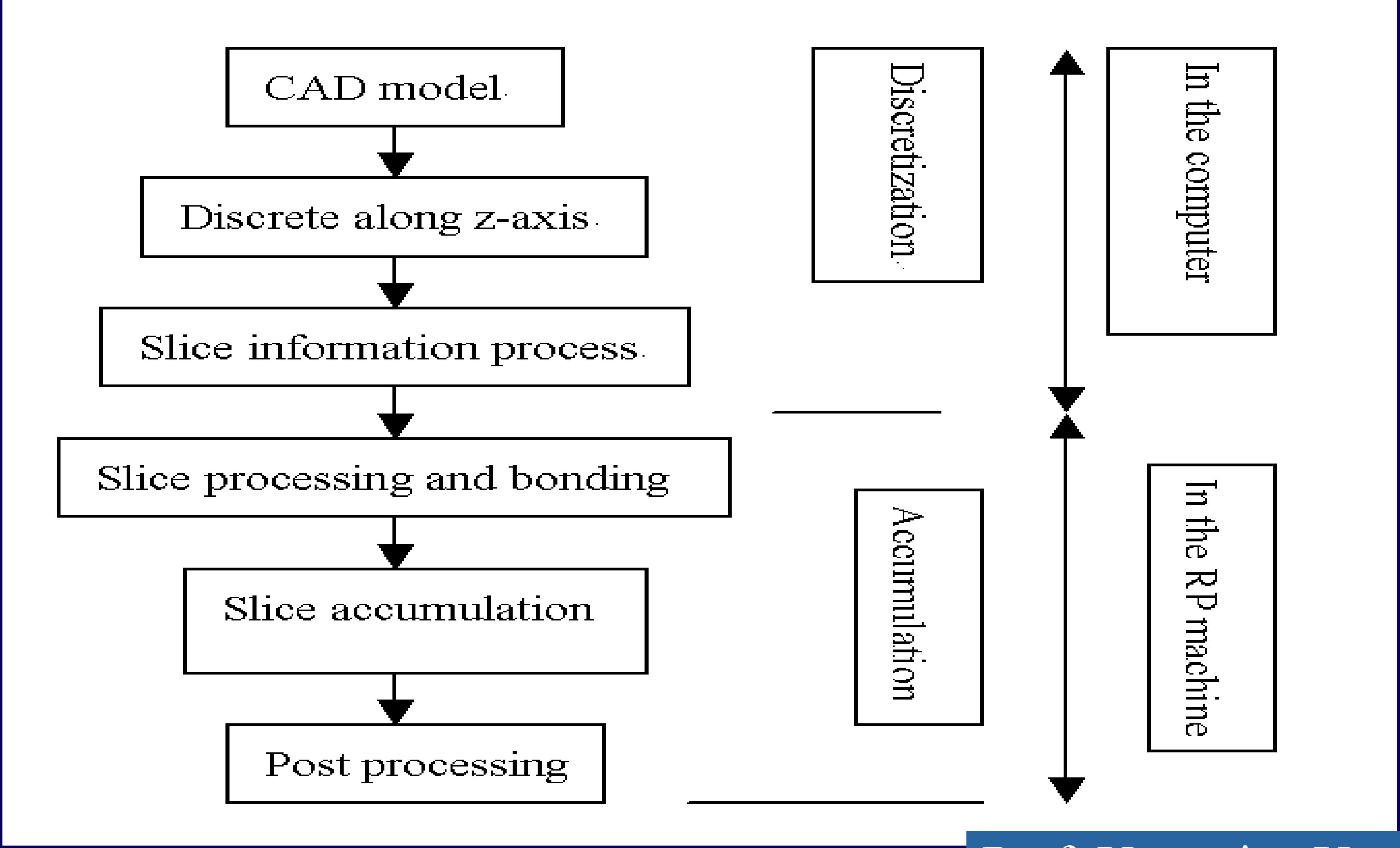
(Stacking, pile Assembling)

- **To acquire definite precision**
  - **Larger number of elements , up to one million.**
  - **Numerous variant parts**

——*CAD* (Computers Aided Design) is required

- **It is difficult to control such numerous material elements manually**
- **Numeric control automatic machine is required to achieve the accumulation**

Discretization/accumulation process diagram



Advantages

– Any complex shapes
– No need of special tools
– Least manual intervention
– Automatic forming, net manufacturing

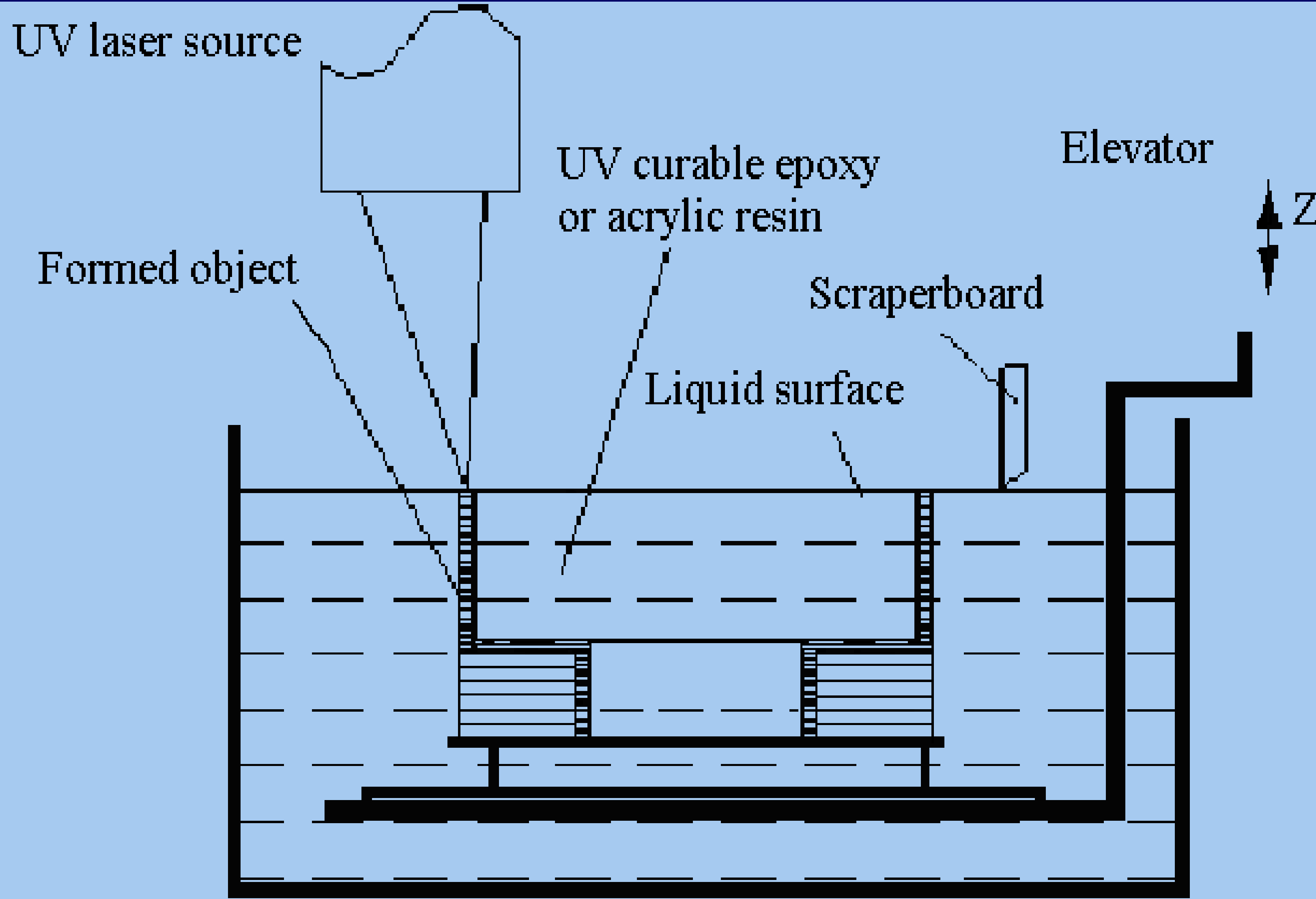
Other Names of FFF

- ***RP***--- Rapid Prototyping
- ***LM***--- Layered Manufacturing
- ***MIM***--- Material Increase Manufacturing
- ***DAM***--- Discretization Accumutation Manufacturing

FFF Technologies

1. **SL – Sterolithography**
2. **LOM---Lamilated Object Manufacturing**
3. **FDM Fused Deposition Modeling**
4. **SLS Selected Laser Sintering**
5. **3DP Three-Dimensional Printer**

1. SL - Sterolithography



Dr. Charles Hull obtained the patent of SL in 1984

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Auro-350

Developed in CLRF, Tsinghua University

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Mandible

Developed in CLRF, Tsinghua University

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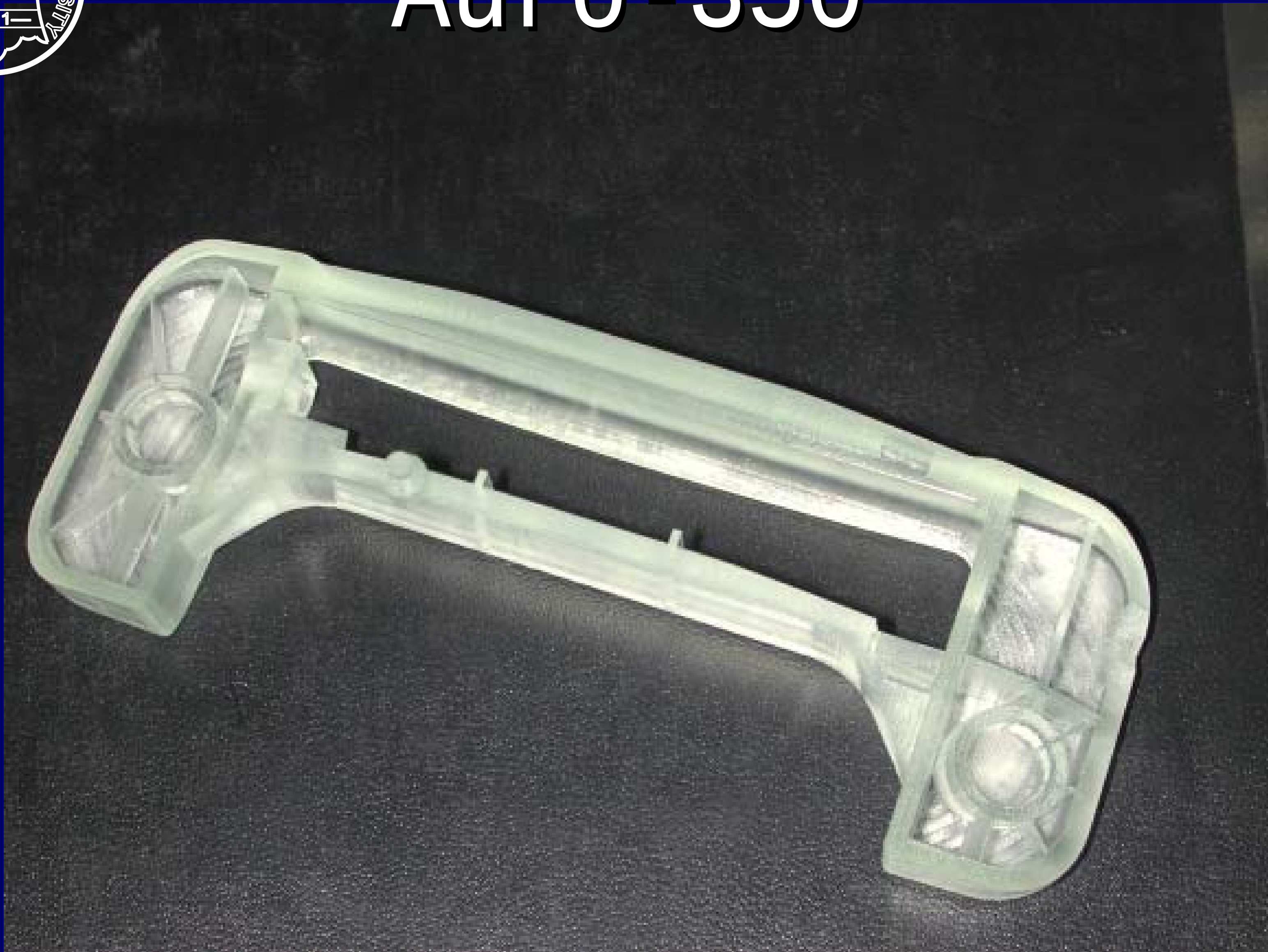
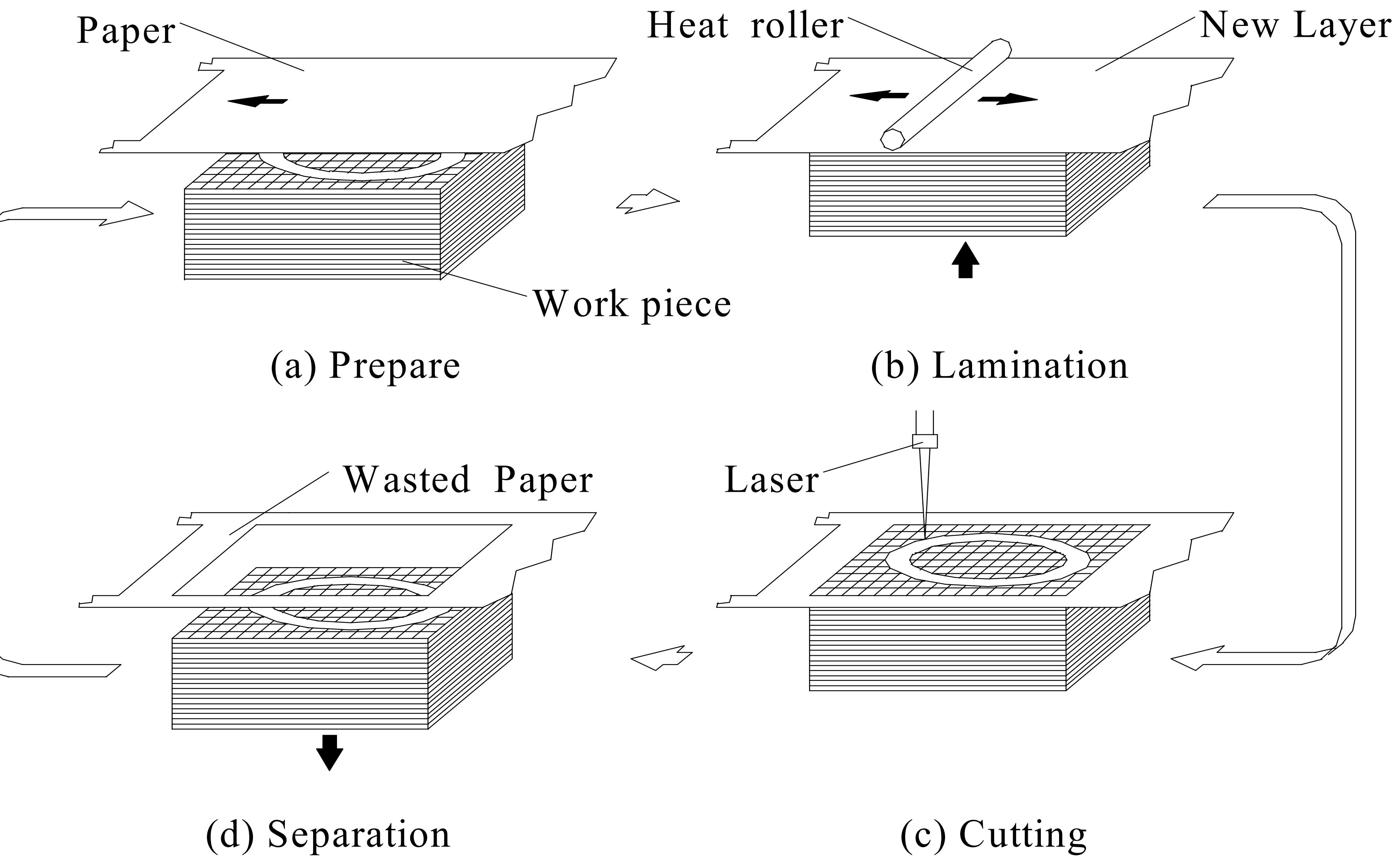
Auro-350



2. LOM---Lamilated Object Manufacturing



SSM-800 Slicing Solid Manufacturing-----SSM

Developed in CLRF, Tsinghua University

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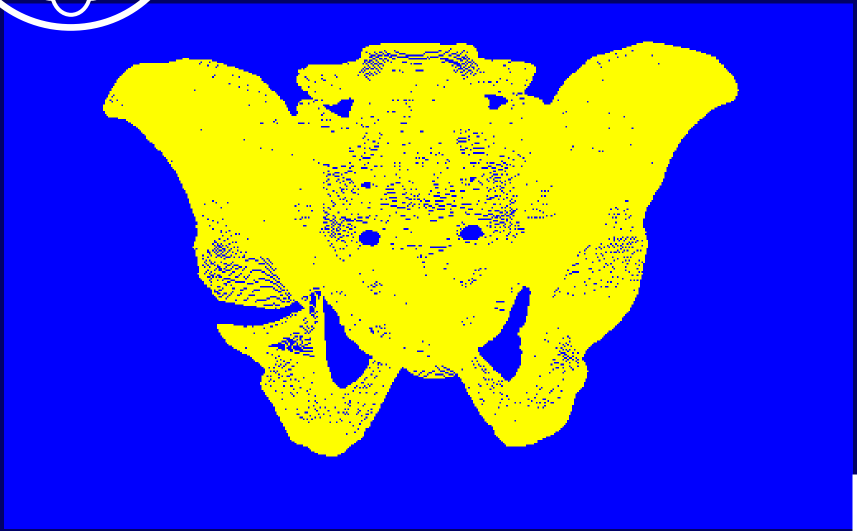
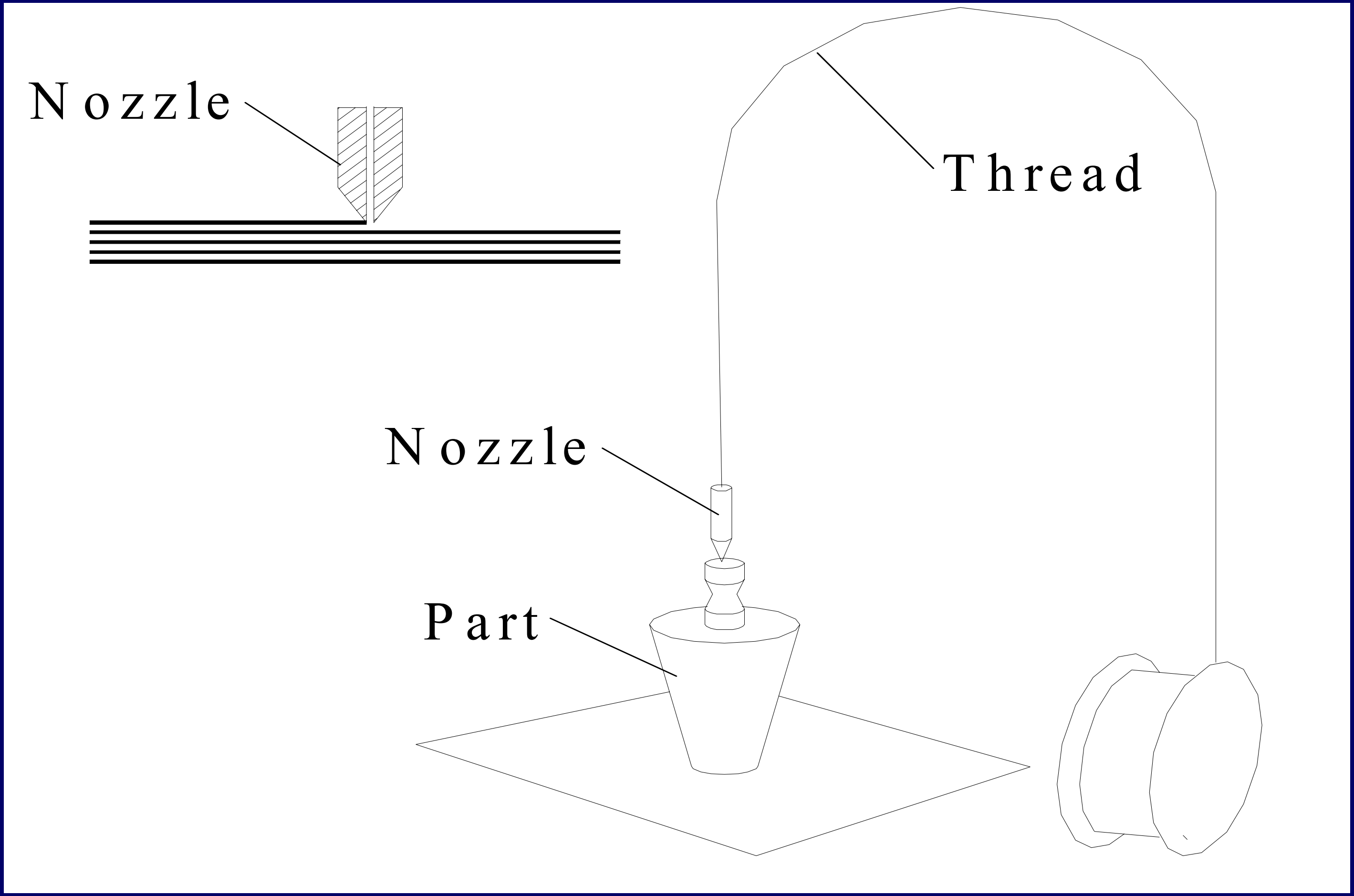


(1) A CAD model of a pelvis reconstructed from CT scanning images

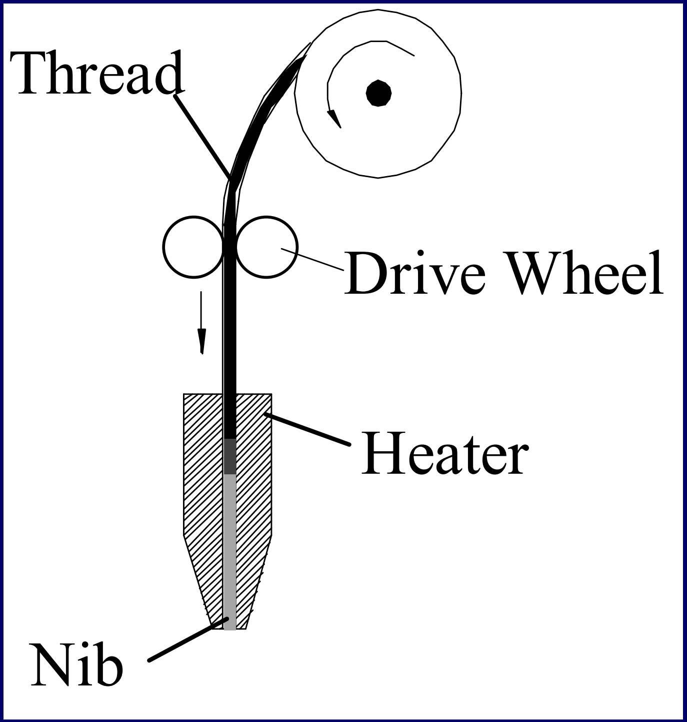
(2) The prototype rapidly produced by LOM (SSM)

3.FDM Fused Deposition Modeling

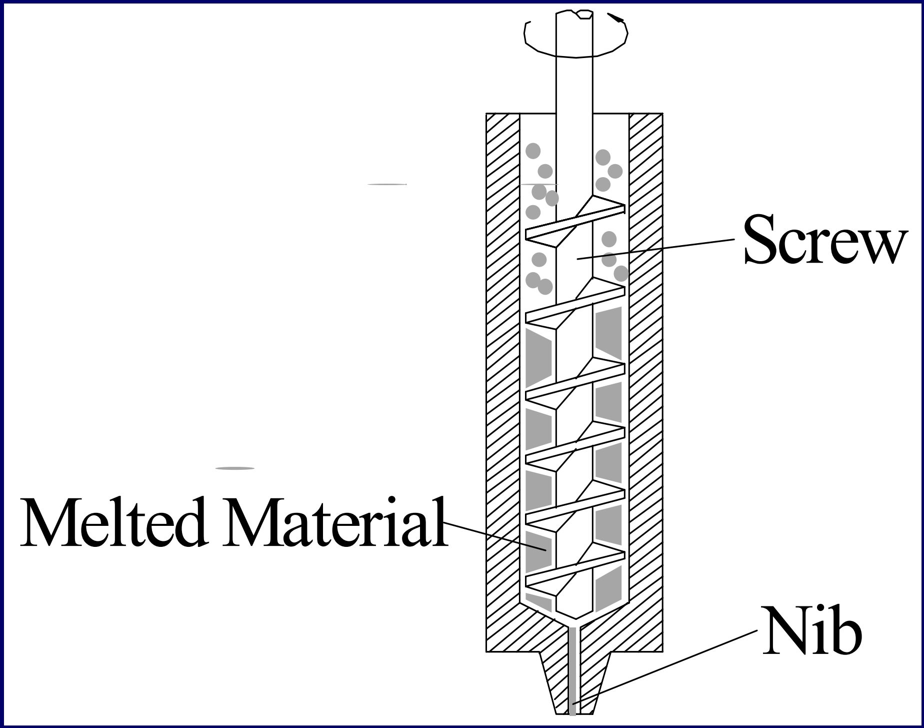


In 1988, ***Dr.Scott Crump*** **proposed FDM process,**
Stratasys Co, **developed FDM commercialized systems**

Nozzles:

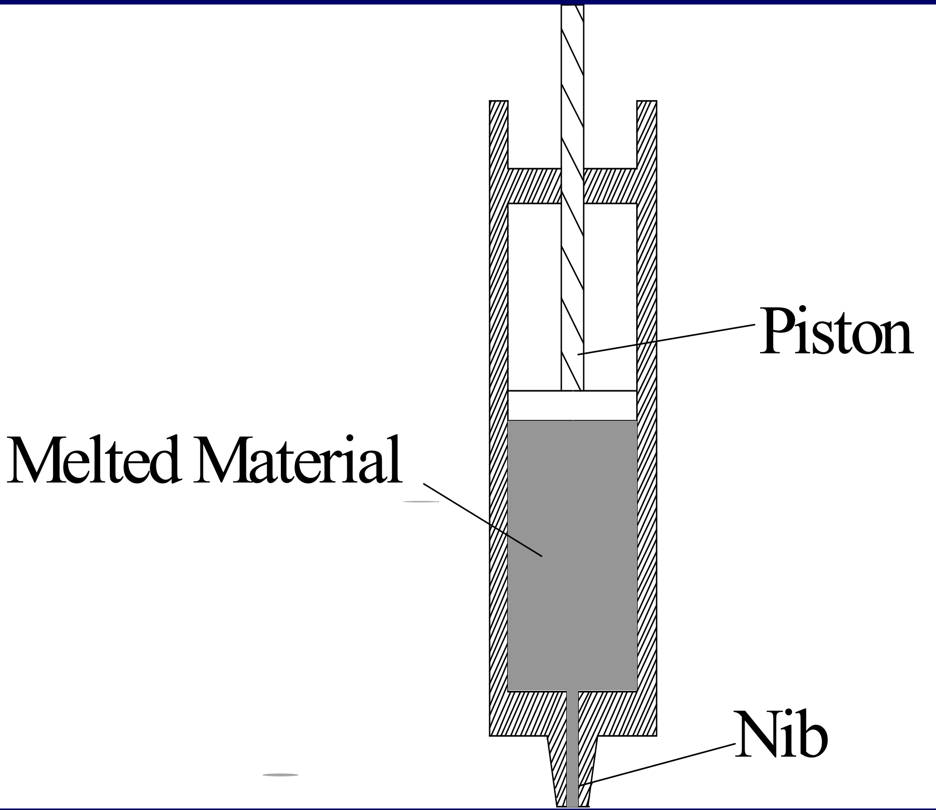


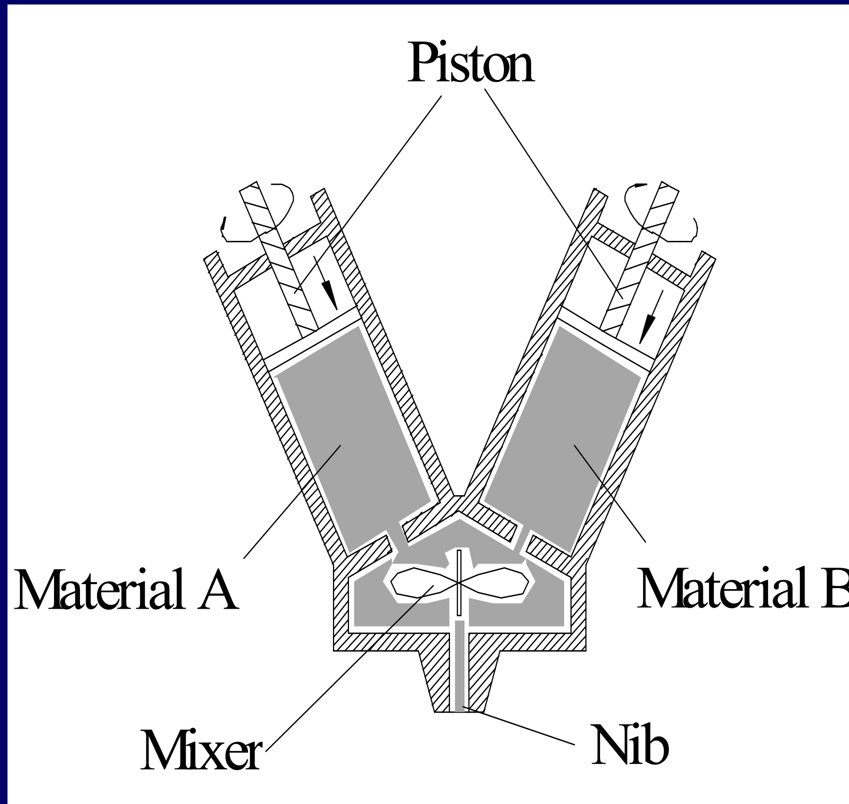
Wheel Drive Nozzle (Filament Material)



Screw Drive Nozzle

Nozzles:



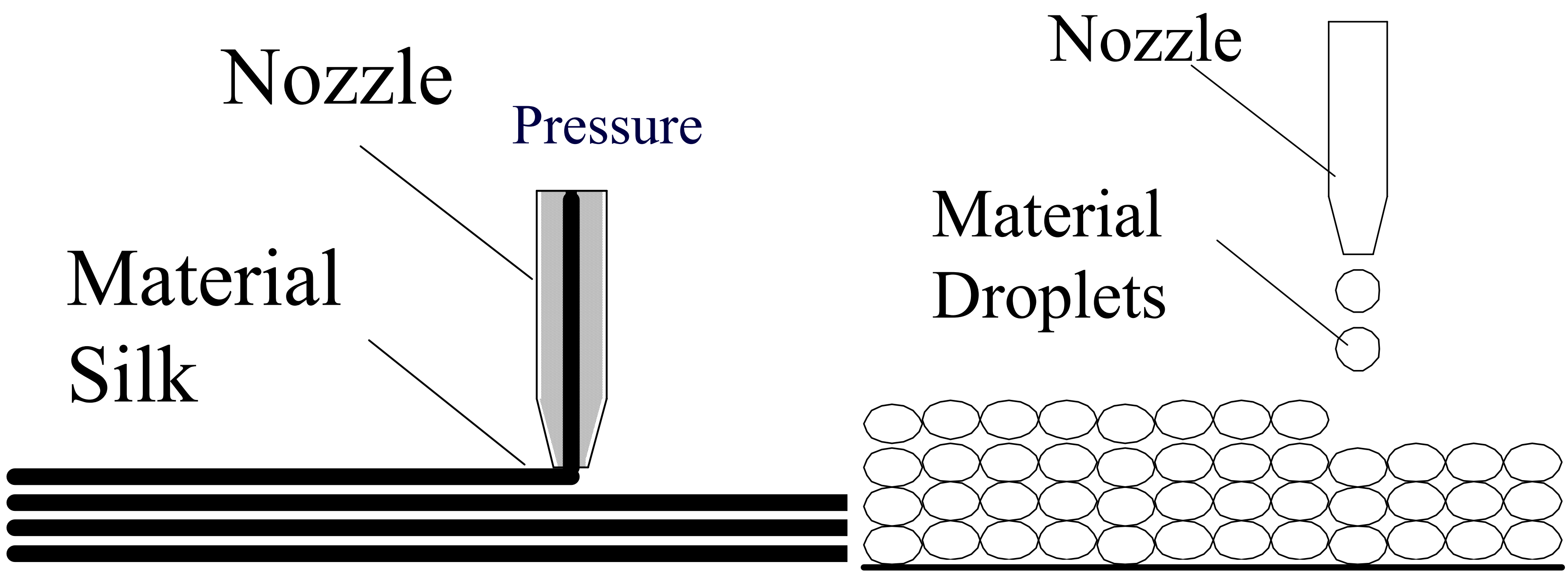


Piston Drive Nozzle

Multi-material Nozzle

Using FFF, extrusion/jetting nozzles, Make out scaffold

Electromagretism Piezoelectricity



(a)Extrusion (b)Jetting

Forming process of the scaffolds

MEM-300-II (Melted Extrusion Manufacturing) System

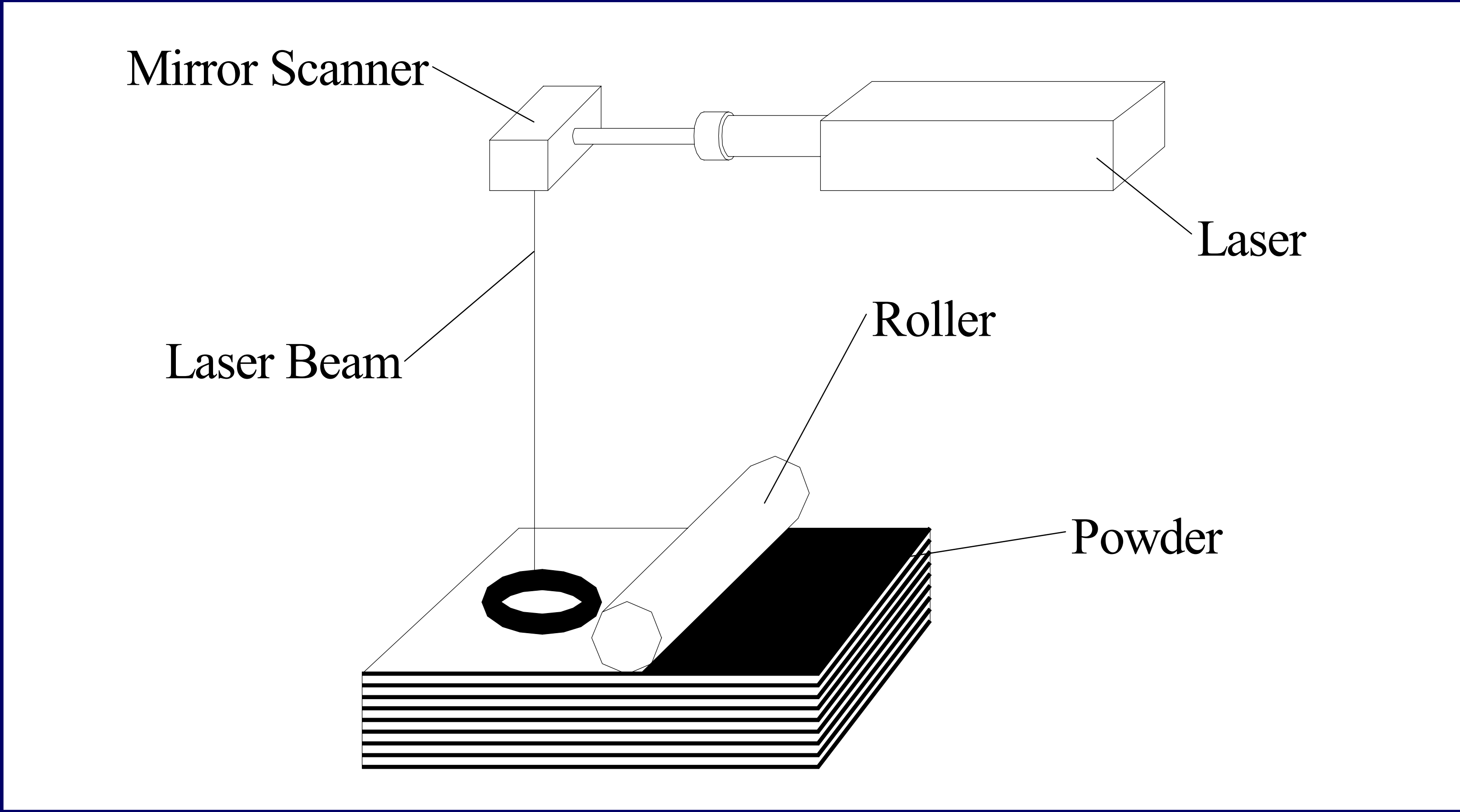
Developed by Tsinghua University

Developed in CLRF, Tsinghua University

The FDM Assemble Model of Eng. Machine

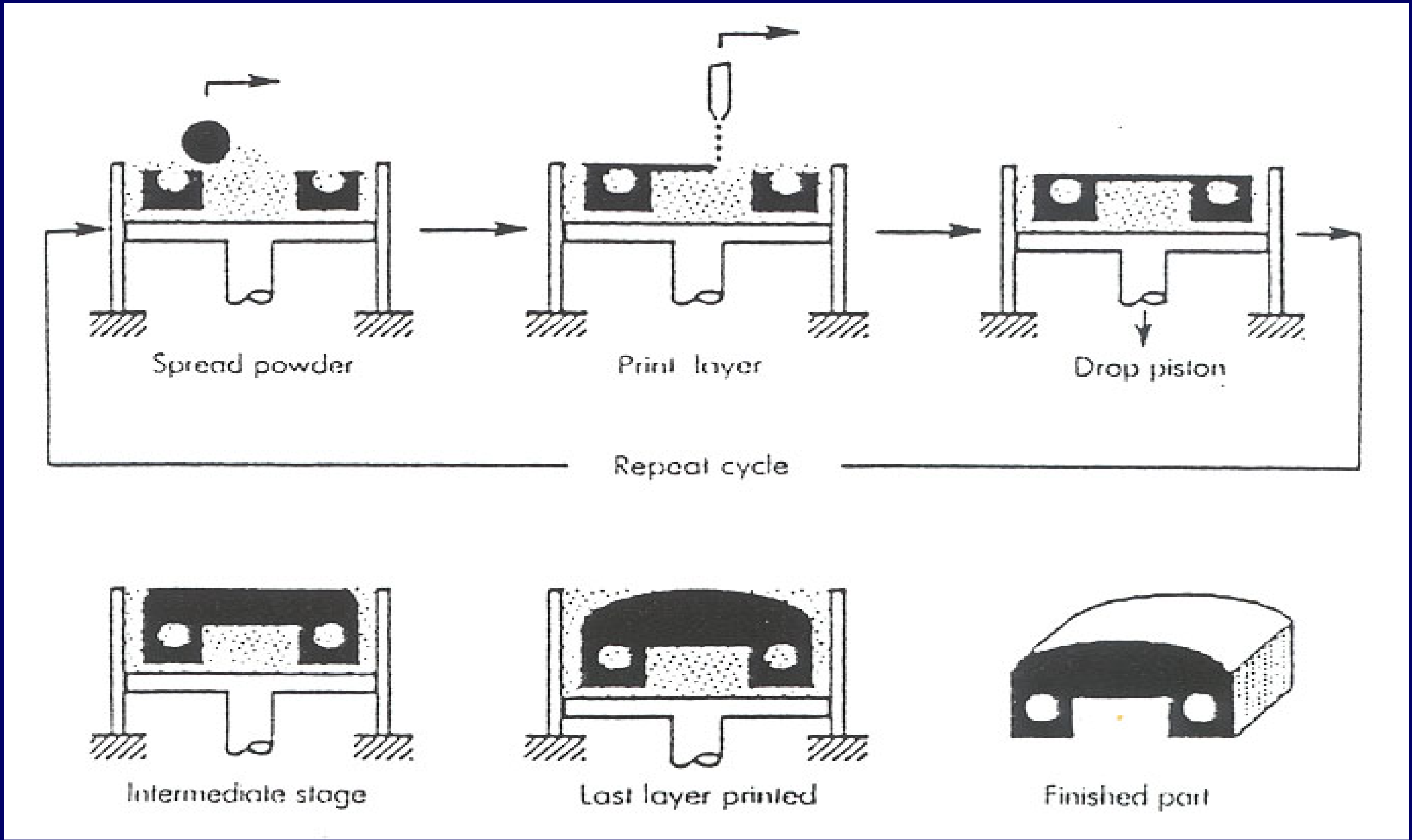
Developed in CLRF, Tsinghua University

4.SLS Selected Laser Sintering



In 1989, C.R.Dechard developed SLS in University of Texas in Austin. DTM Co. developed its commercialized systems.

5. 3DP Three-Dimensional Printer



In 1989, Emanuel M. Such developed in MIT. Z-Coop Co. bought the patent and developed the commercialized system.

The 3DP Model of Toy

FDM **(MEM) and** ***3DP*** **are the most important FFF Technologies for Tissue Eng. Scaffold**

Scaffold has

* Complex structure

* Complex material gradient

* Pore gradient

* Pore rate

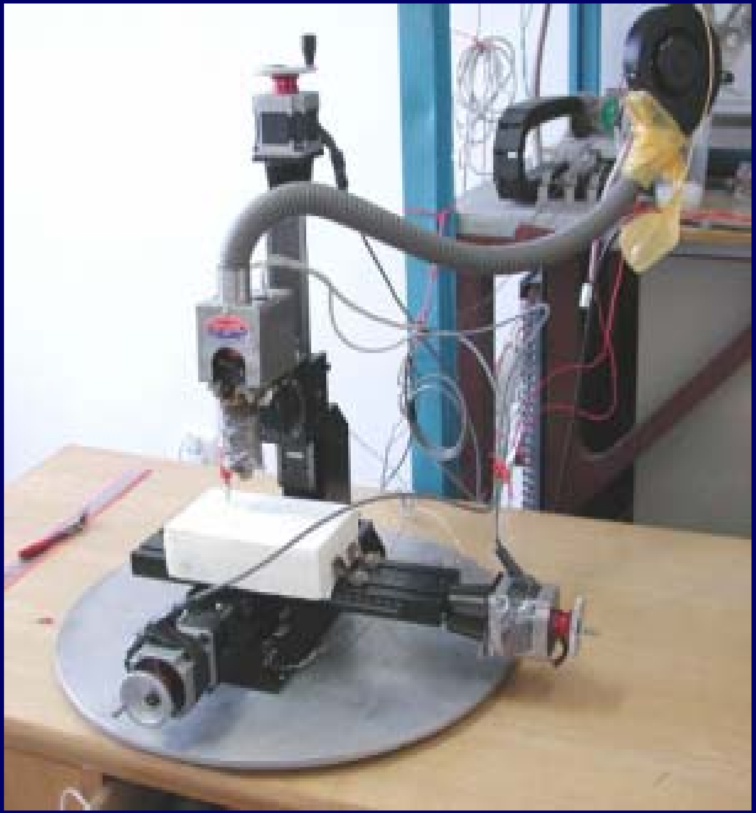
Scaffold characteristics

- Three-dimensional and highly porous with a interconnected pore network for cell growth and flow transport of nutrients and metabolic waste

- Biocompatible and bioresorbable with a controllable degradation and resorption rate to math cell/tissue growth in vitro and /or in vivo

- Suitable surface chemistry for cell attachment, proliferation, and differentiation
- Mechanical properties to match those of the tissues at the site of implantation
- Be easily processed to form a variety of shapes and sizes

Opening System



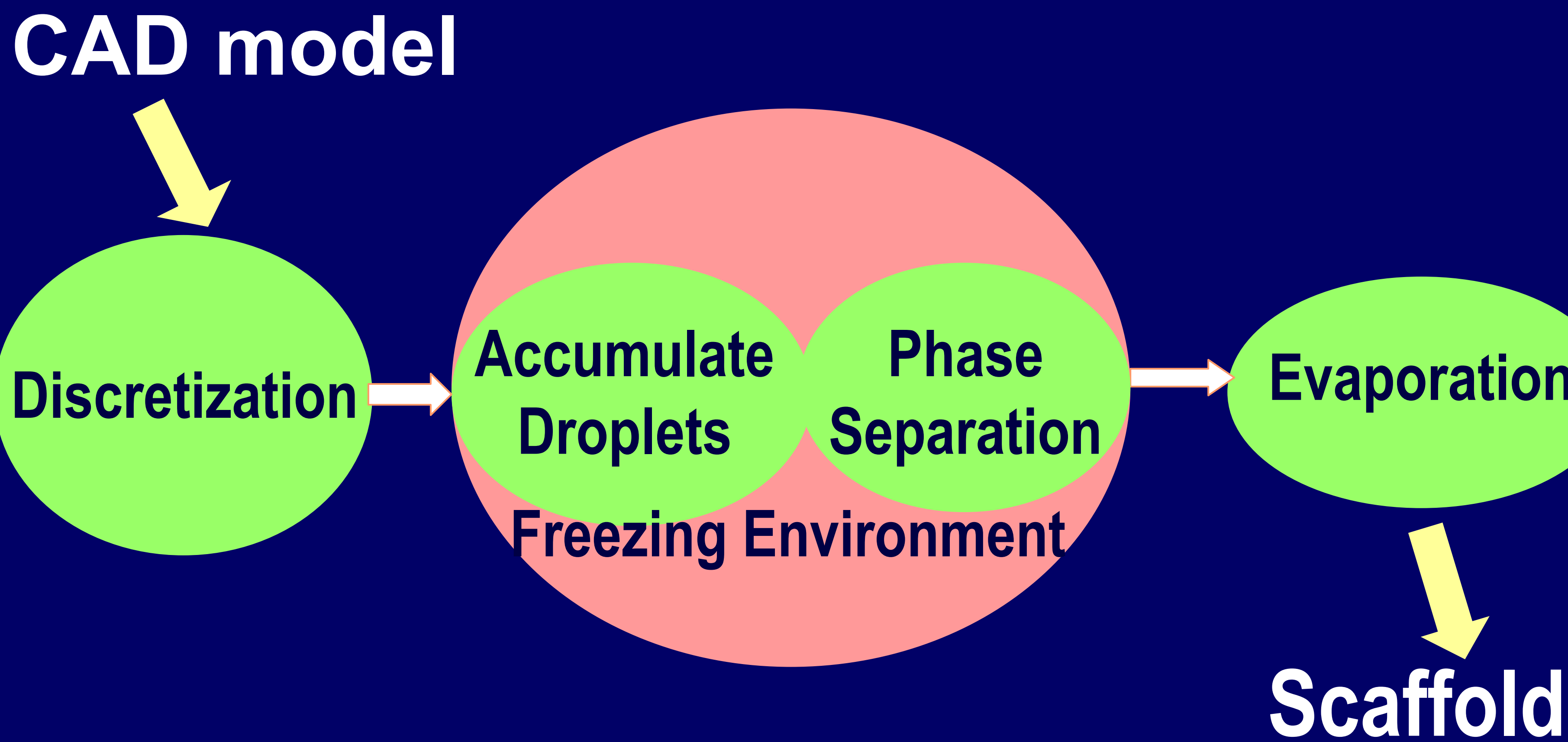
MedForm

Developed in CLRF, Tsinghua University

Desk top biomaterial forming Machine

Developed in CLRF, Tsinghua University

LDM——Low Temperature Deposition Manufacturing



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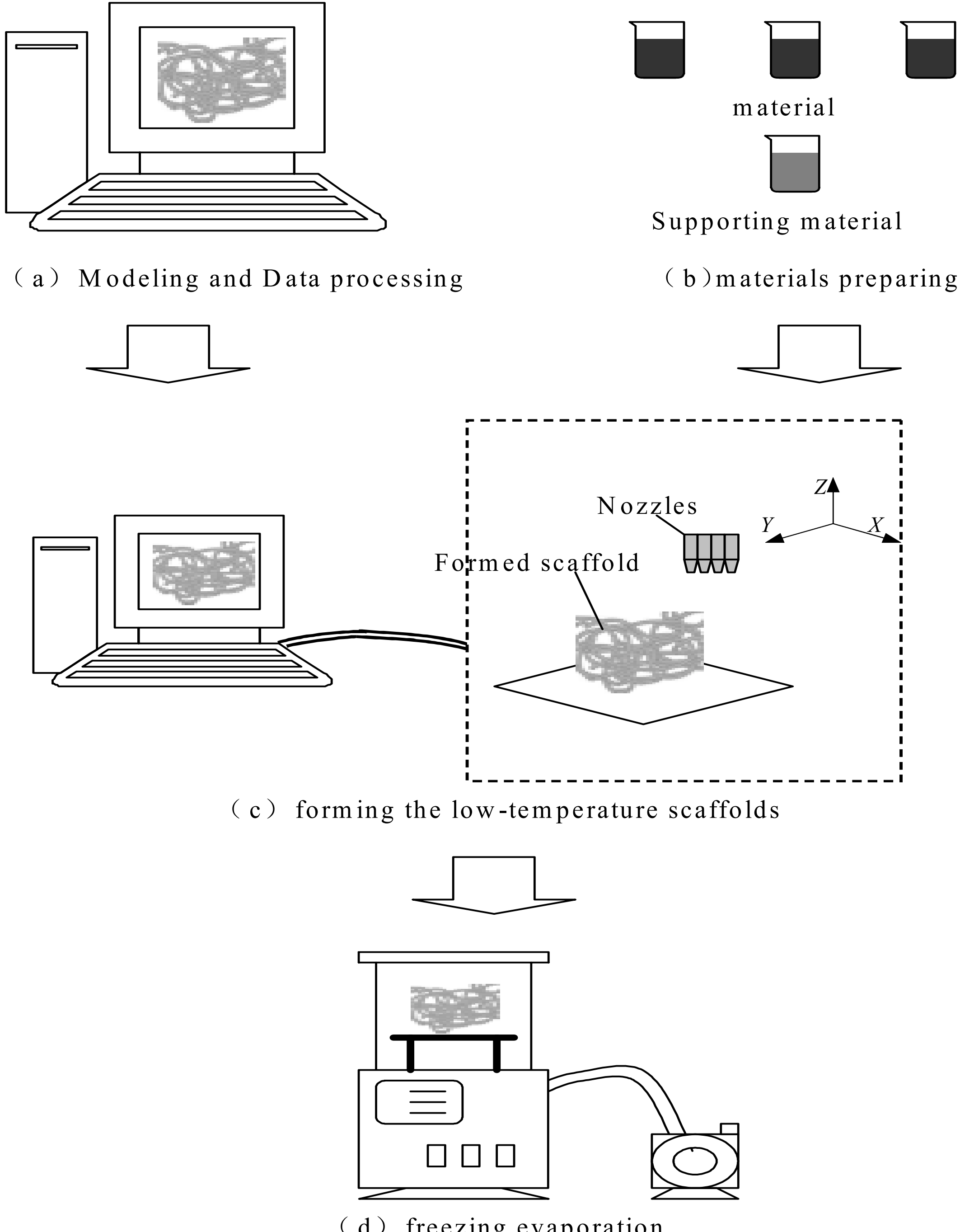
LDM


material
Supporting material
（a） Modeling and Data processing
（b）materials preparing
Nozzles
Z
Y
X
Formed scaffold
（c） forming the low-temperature scaffolds
（d） freezing evaporation

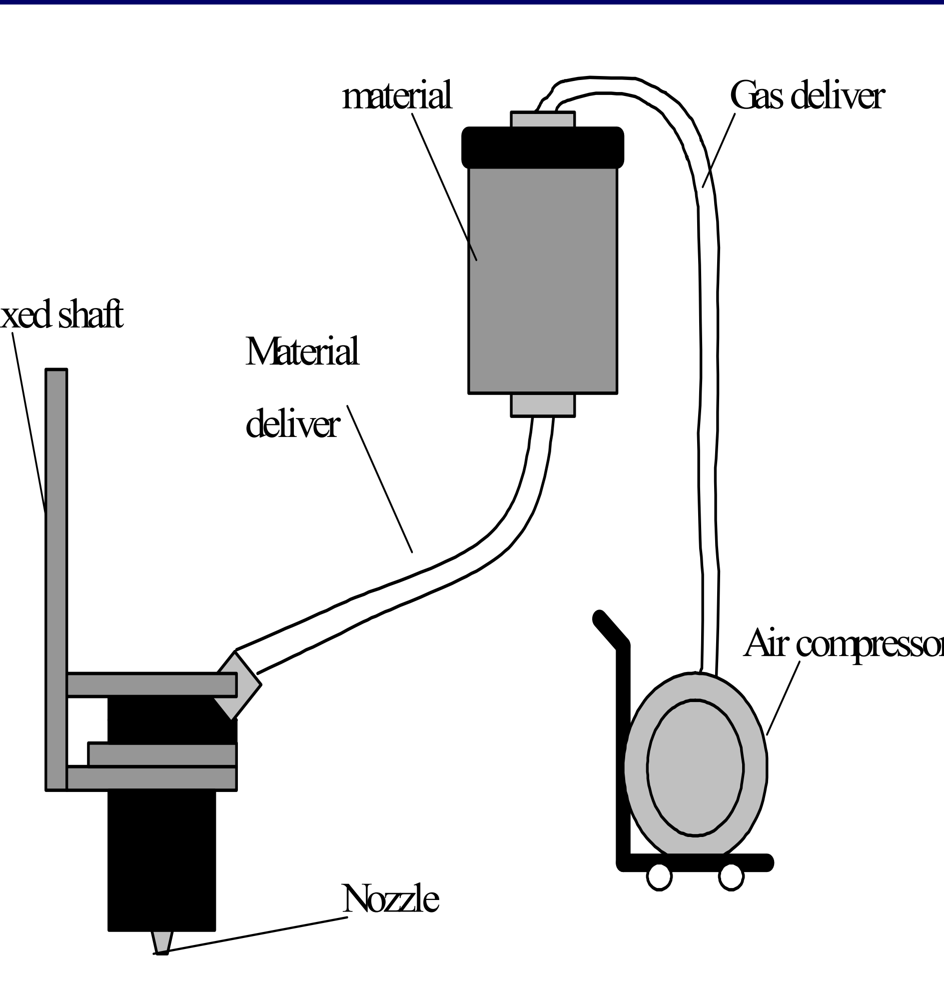
The requirements of numeric control for LDM:

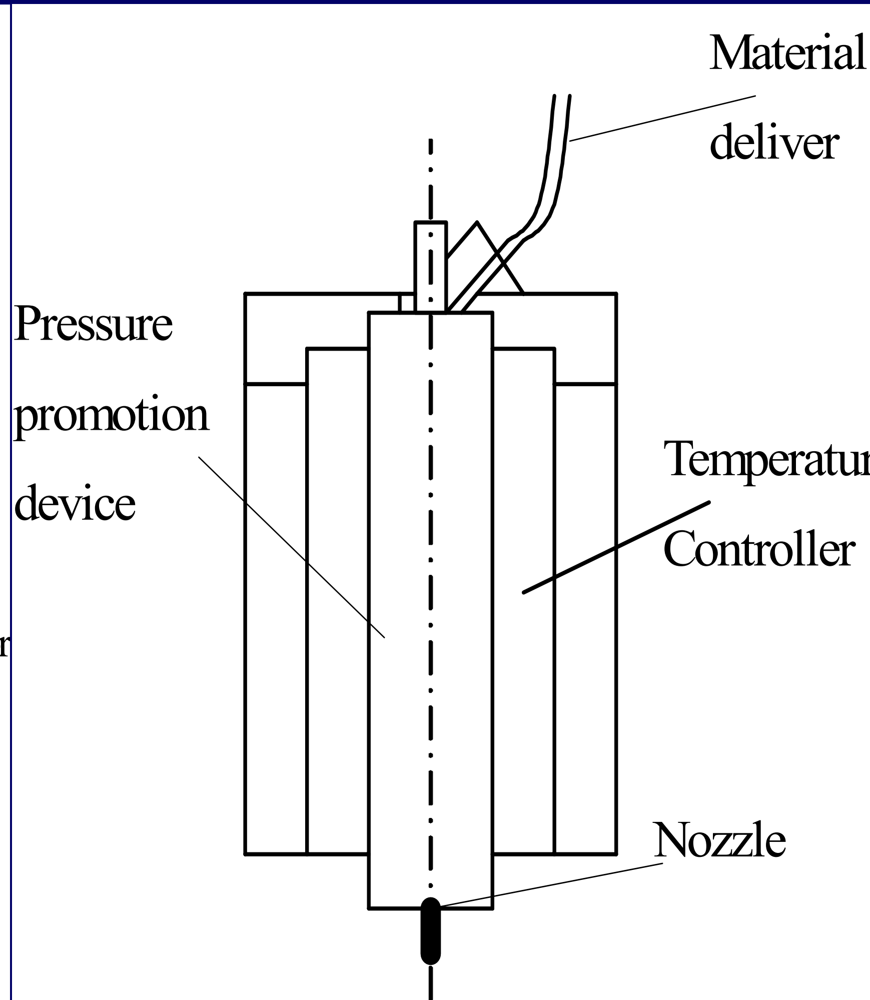
- The accumulating process of biomaterials is the same as (FDM)---modeling technology.
- There are several materials on the one layer during forming.
- Layer contour scan mode and point-to-point control mode are necessary at the same time.

The requirements of environment for LDM:

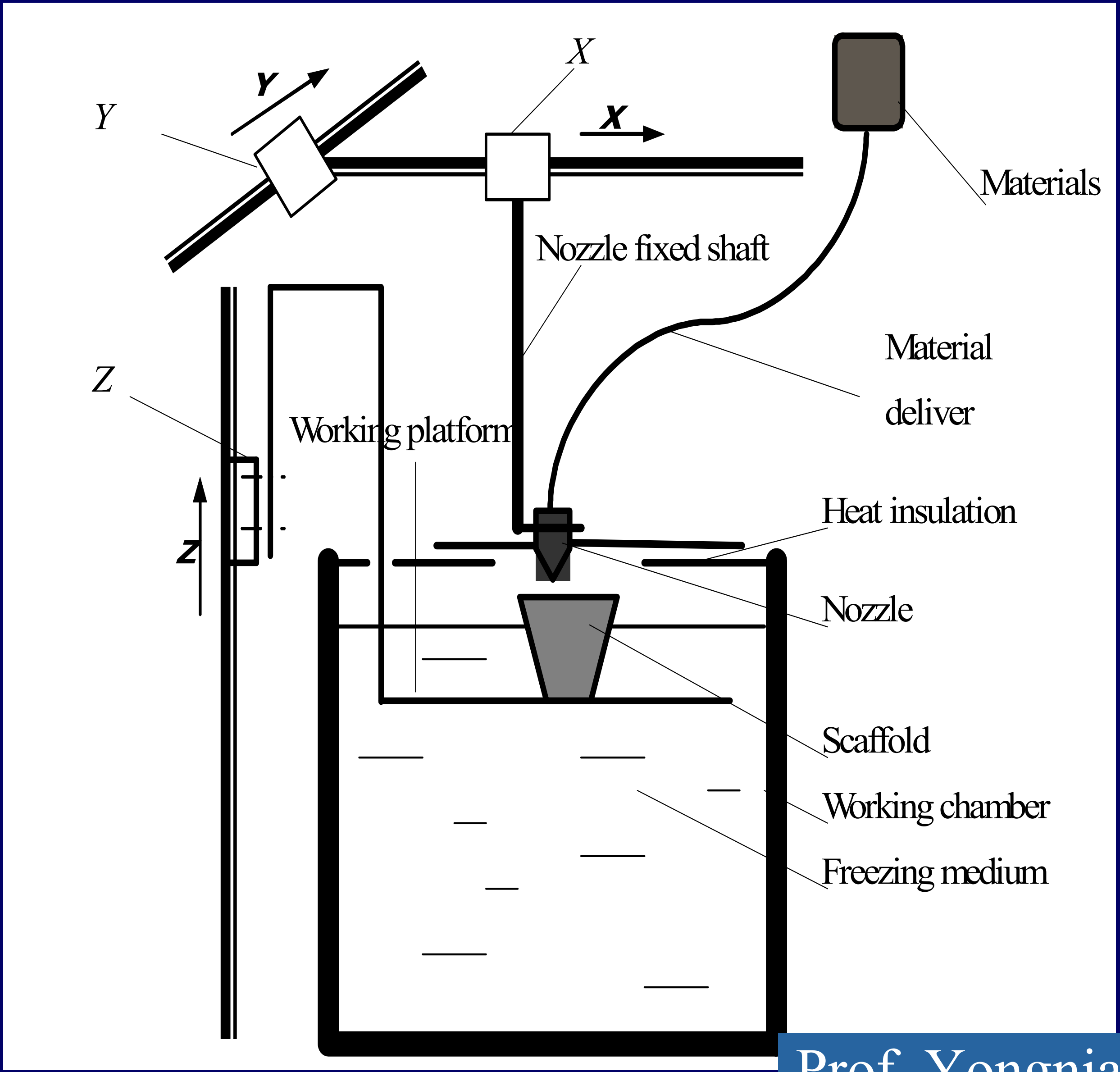
- Temperature, it needs to keep certain low within the forming environment.
- During the forming process, it needs to keep the bio-activity of the materials unchanged under the temperature of the nozzles.

Every nozzle must have independent traveling system to convey materials





Forming environment model (1)



Liquid medium

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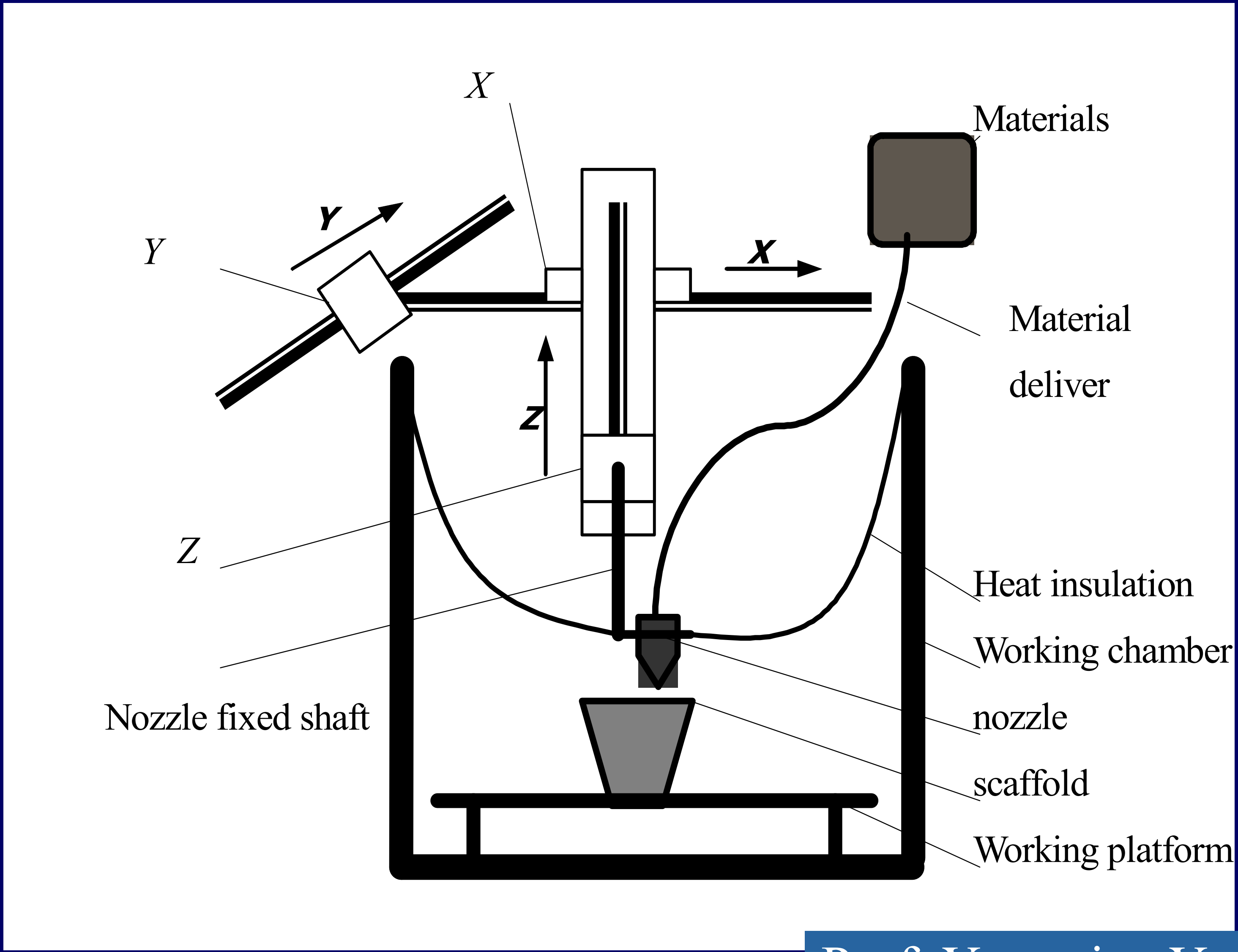
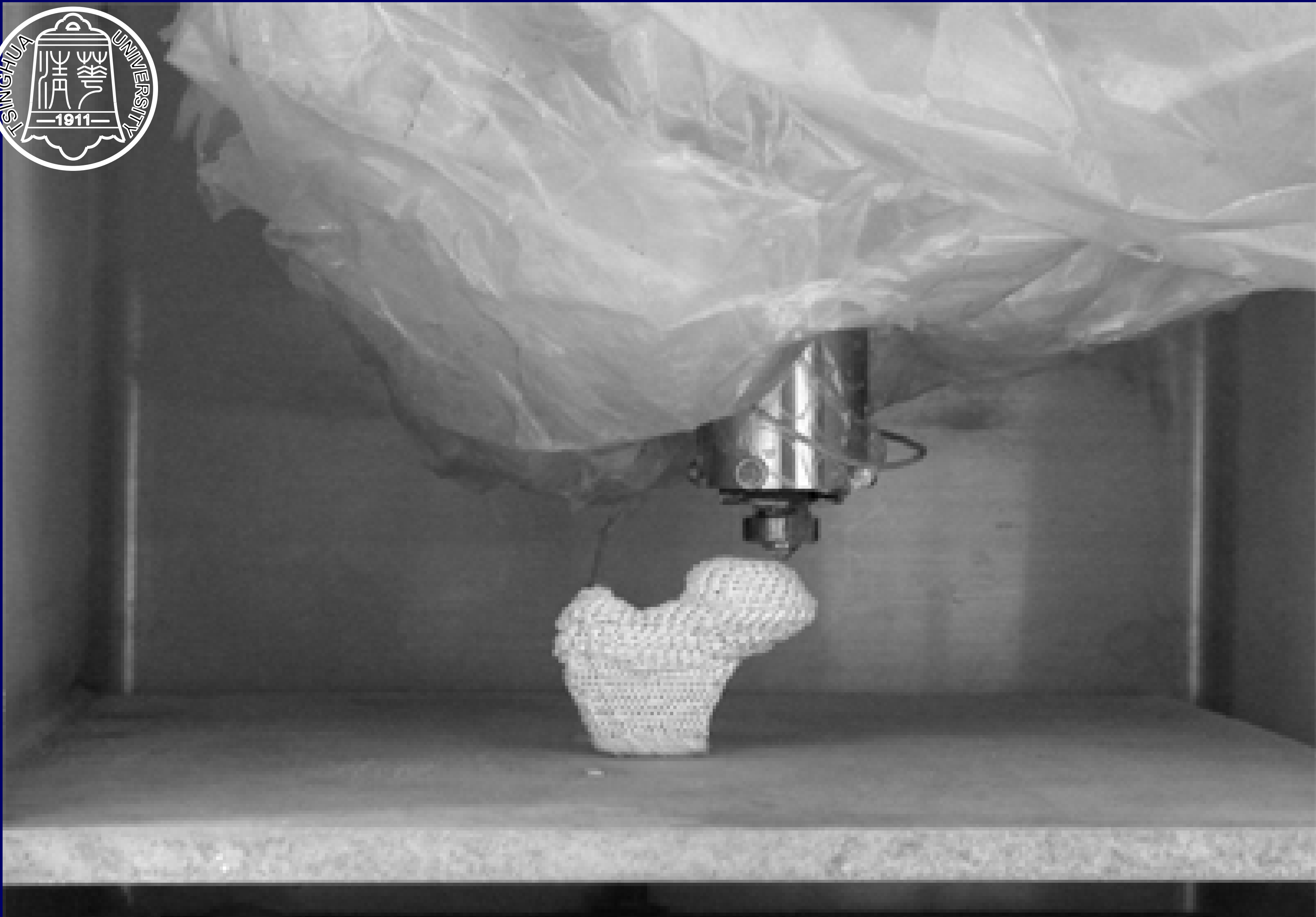
Forming environment model (2)

Gas medium



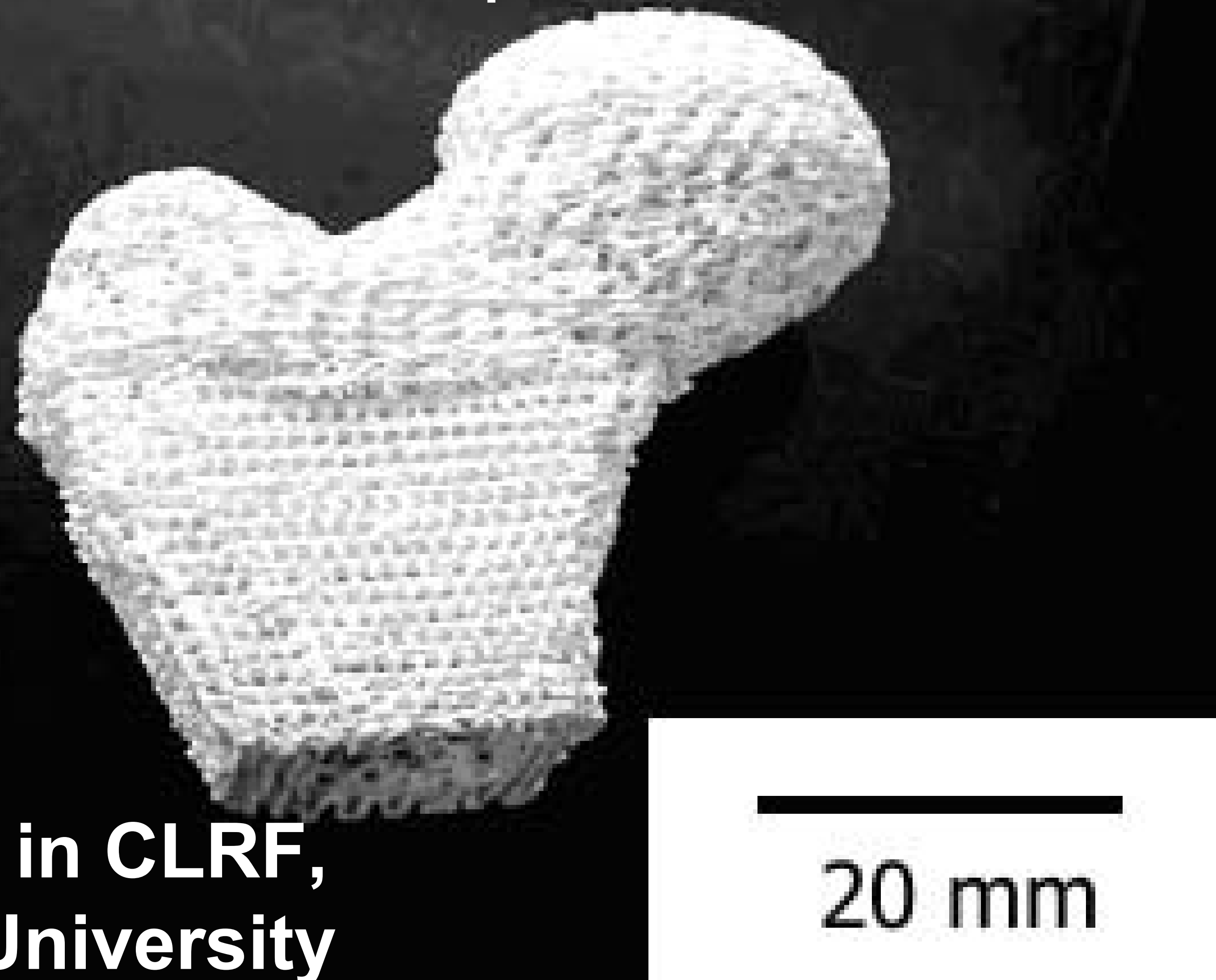
Bio-material Forming Platform

Developed in CLRF, Tsinghua University



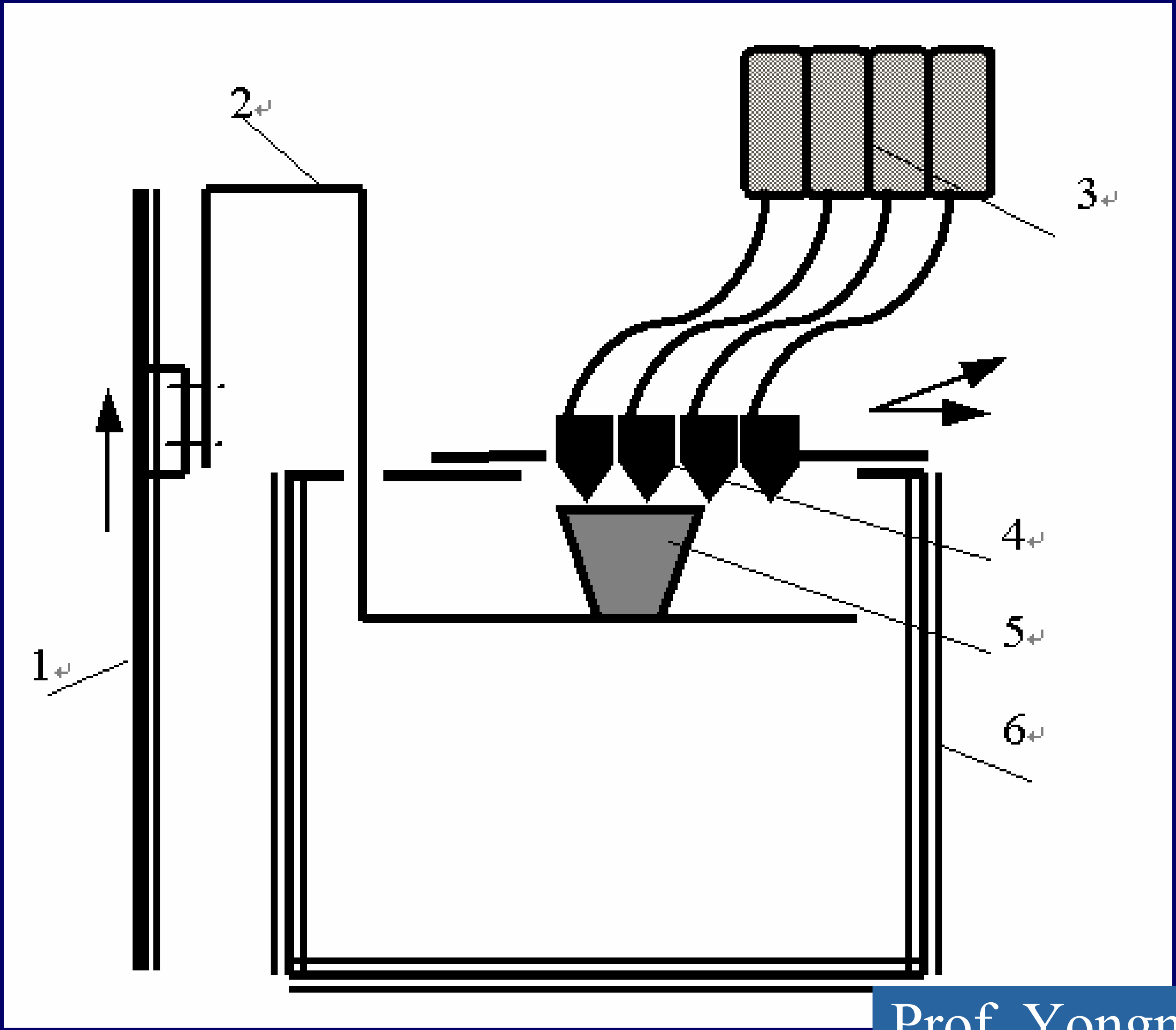
Developed in CLRF, Tsinghua University

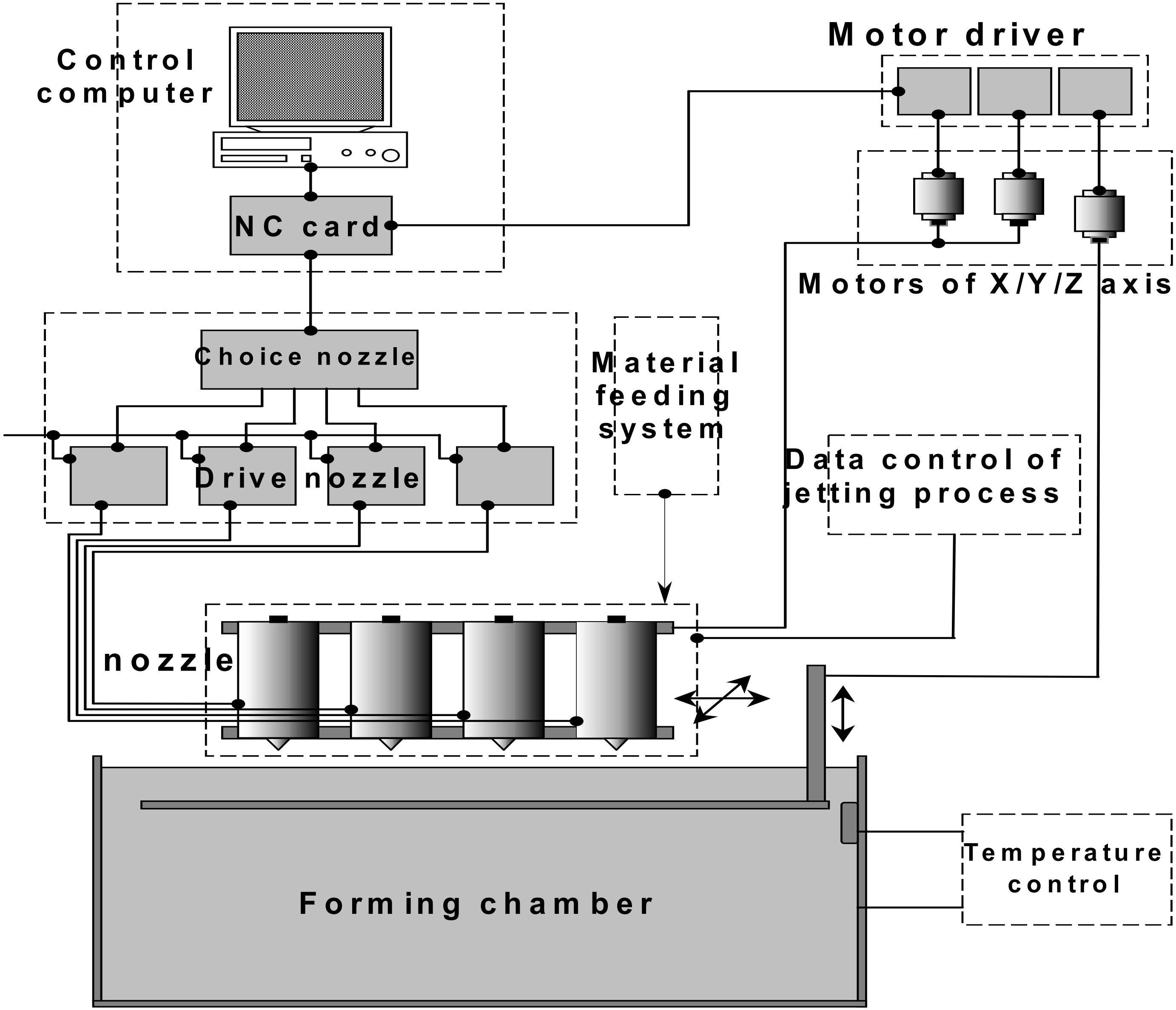
Scaffold poly (L-lactic acid) Tricalcium Phosphate



Developed in CLRF, Tsinghua University

Multi-Nozzles system of Scaffold form Machine





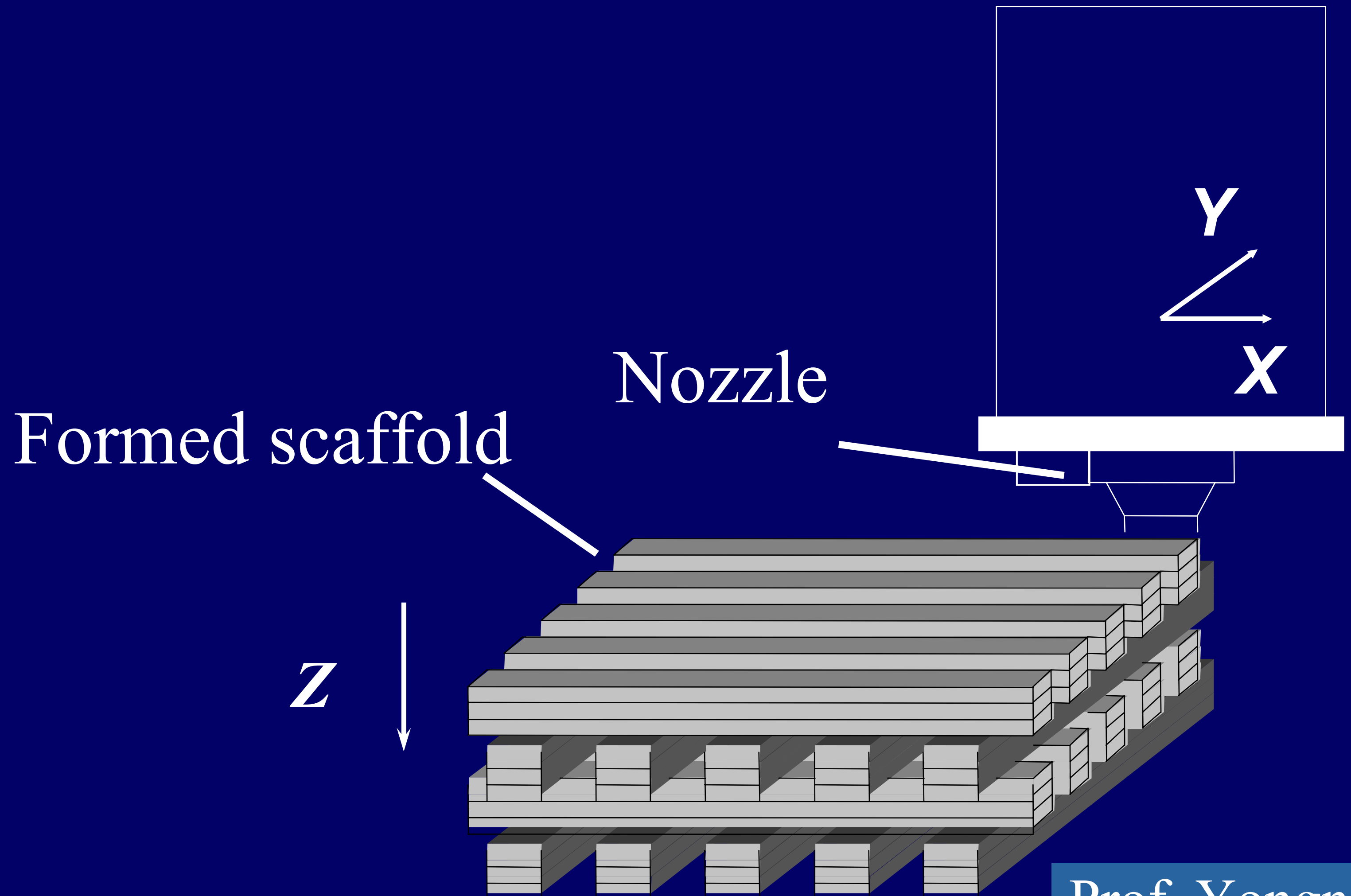
Bio-material RP Forming Machine System

name	TissForm		
Forming material	Biocompatible materials		
Number and type of nozzles	Screw pump	Electro-magnetism valve	Piezoelectricity crystal
	2	1	1
NC card	American Del ton company Pmac NC card		
Environment	-30℃—30℃		
Forming space	200*200*200 mm^3		
Scan speed	70 mm/s		

Tiss-Form Machine

Developed in CLRF, Tsinghua University

Illustration of forming process of scaffolds in the LDM system



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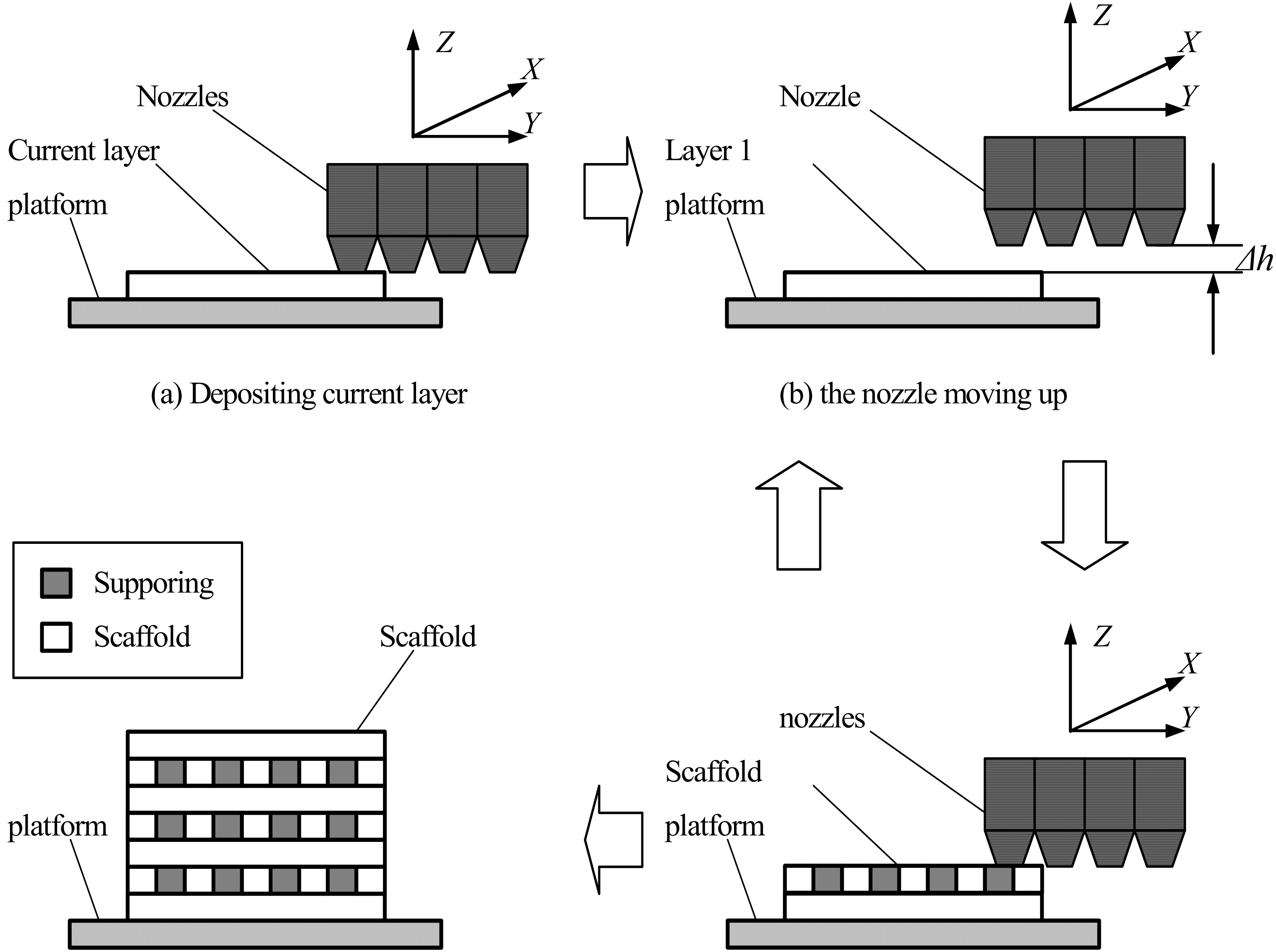


(a) Depositing current layer

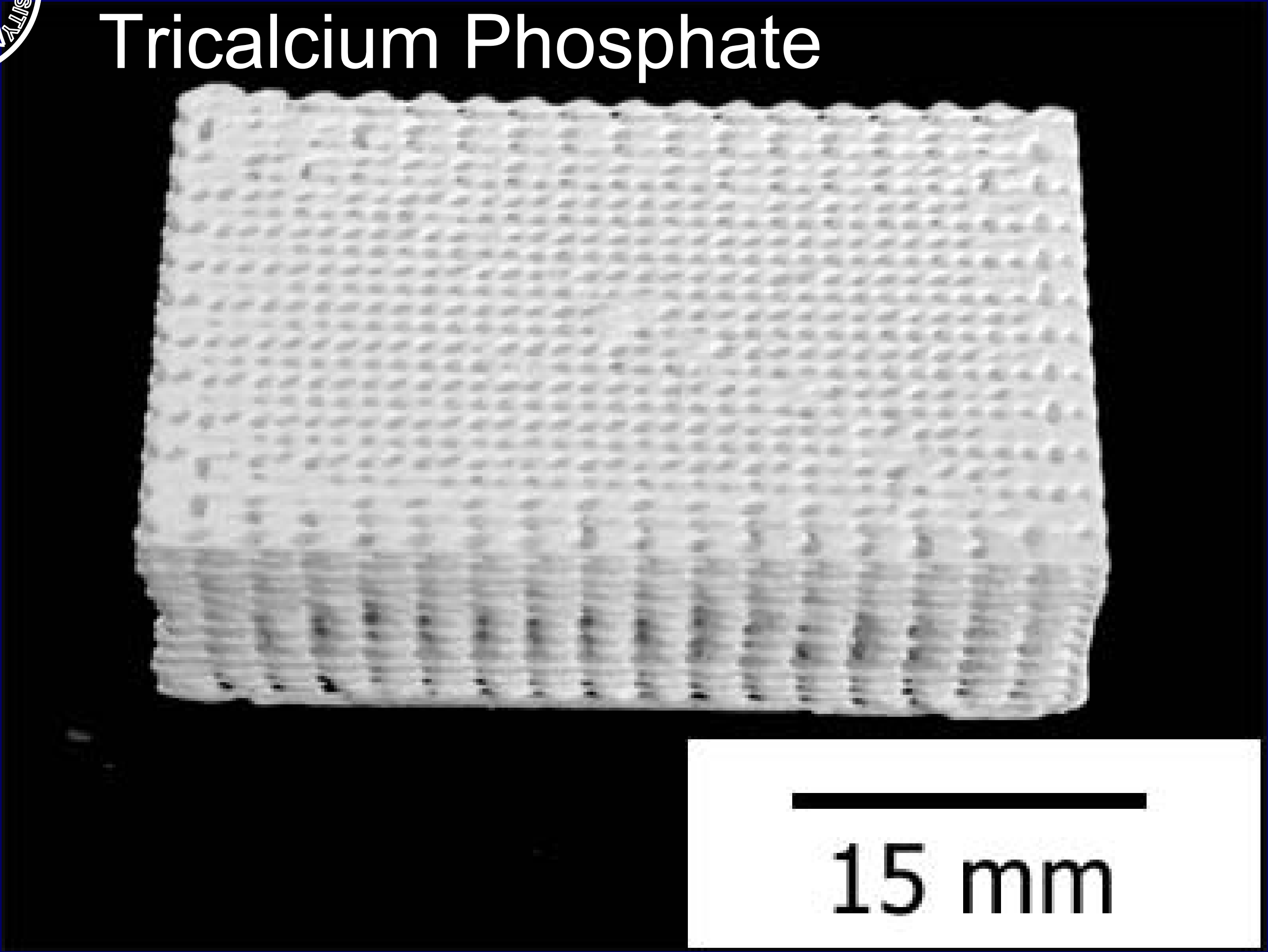
(b) the nozzle moving up

(d) finished parts

(c) depositing the next layer

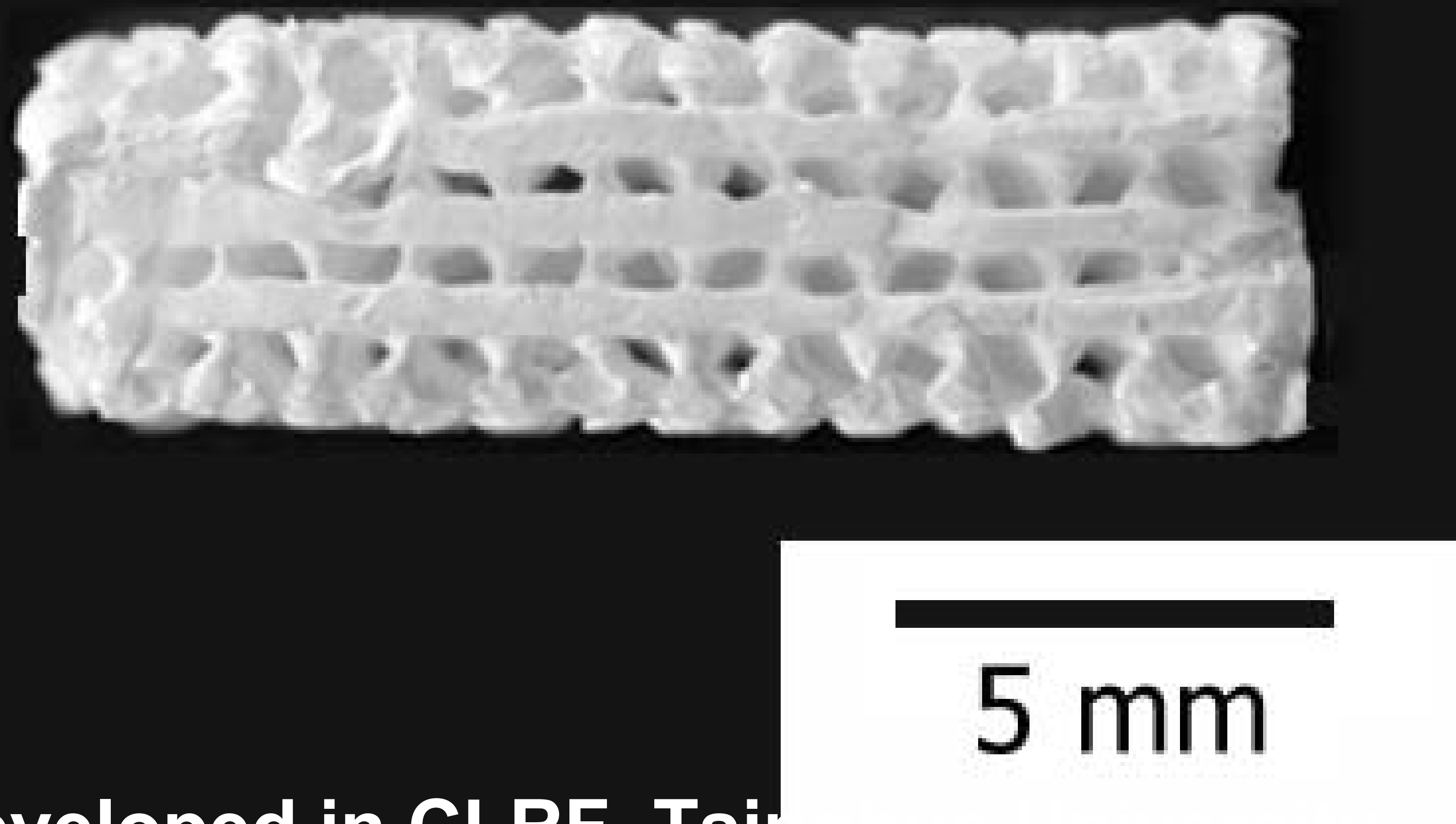
Scaffold poly (L-lactic acid)

Tricalcium Phosphate



Developed in CLRF, Tsinghua University

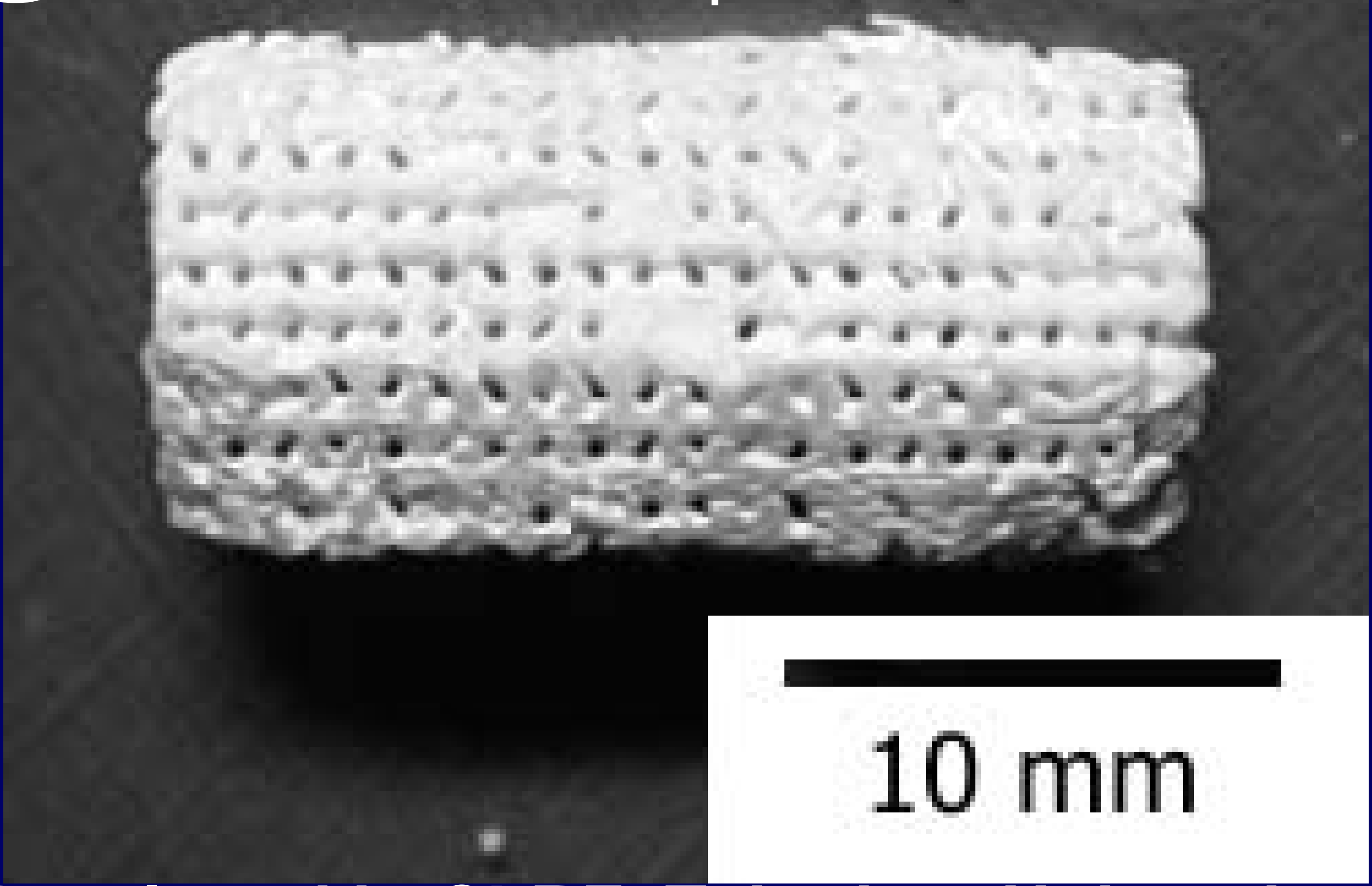
Scaffold poly (L-lactic acid)
Tricalcium Phosphate



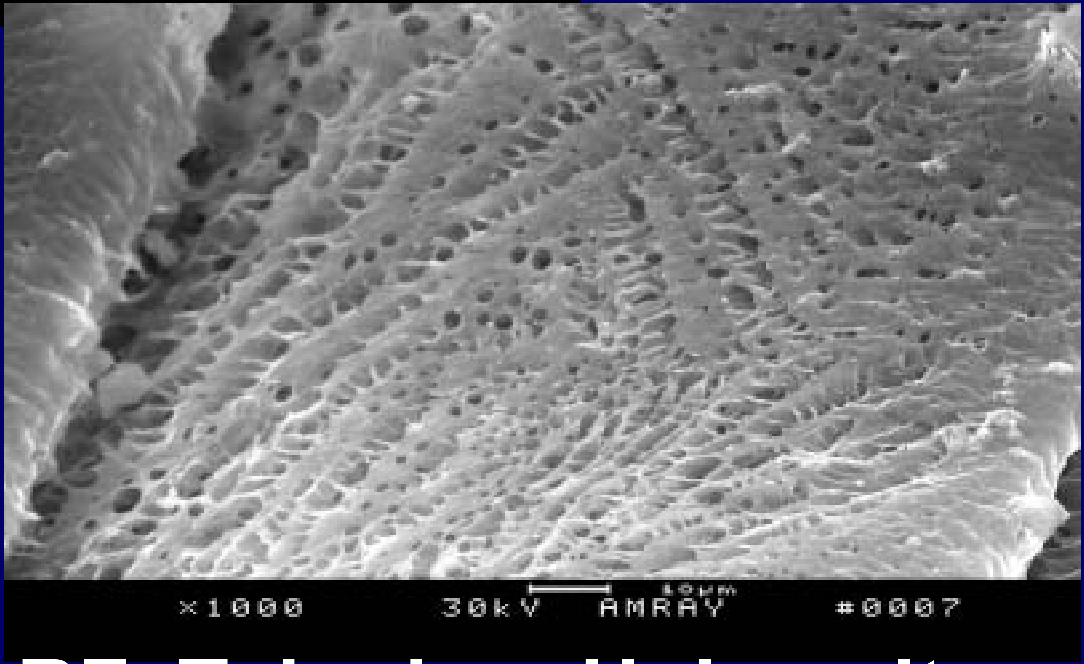
Developed in CLRF, Tsinghua University

Scaffold poly (L-lactic acid)

Tricalcium Phosphate



Developed in CLRF, Tsinghua University



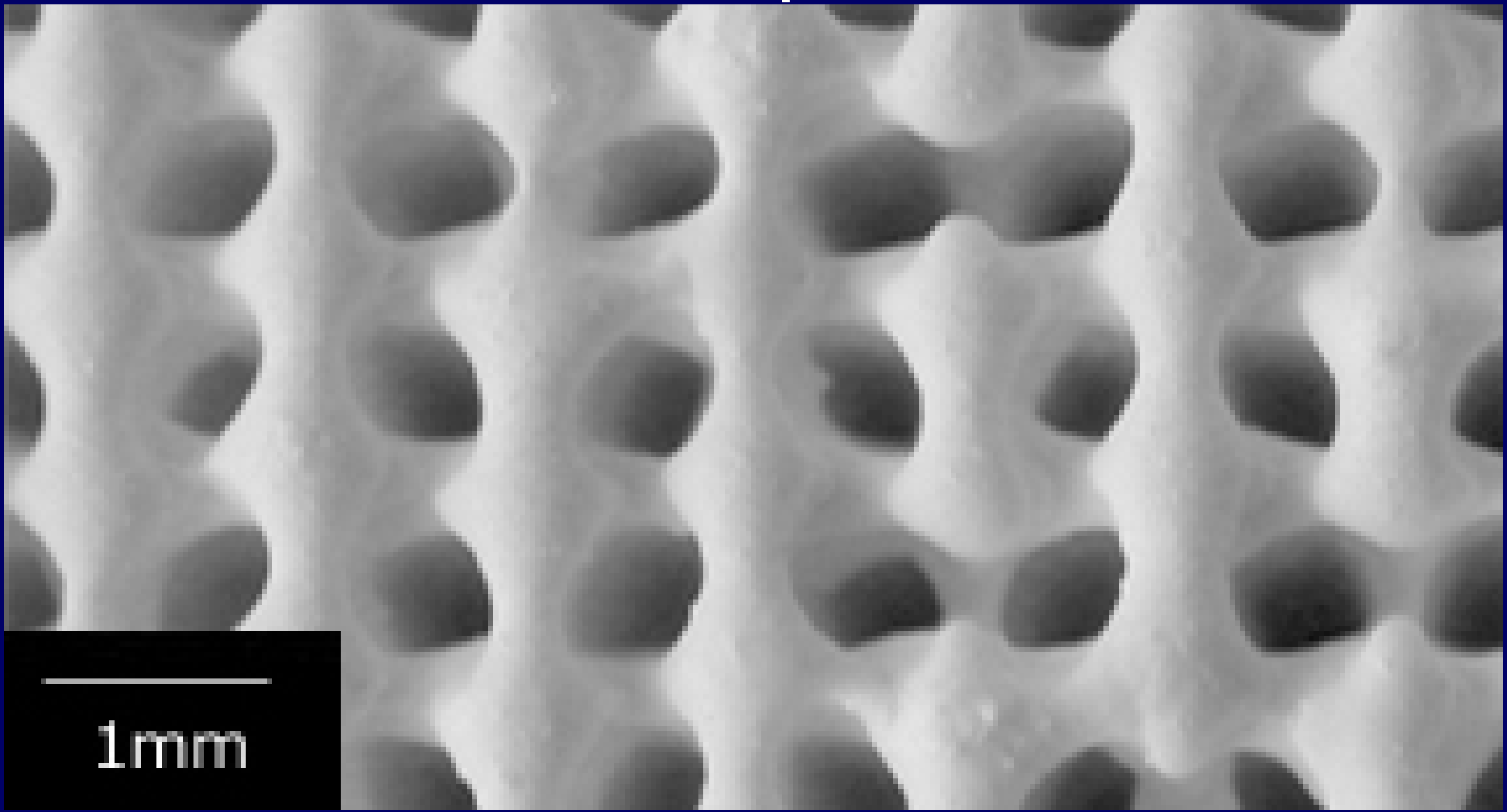
Porosity

85~90%

Developed in CLRF, Tsinghua University

Scaffold poly (L-lactic acid)

Tricalcium Phosphate



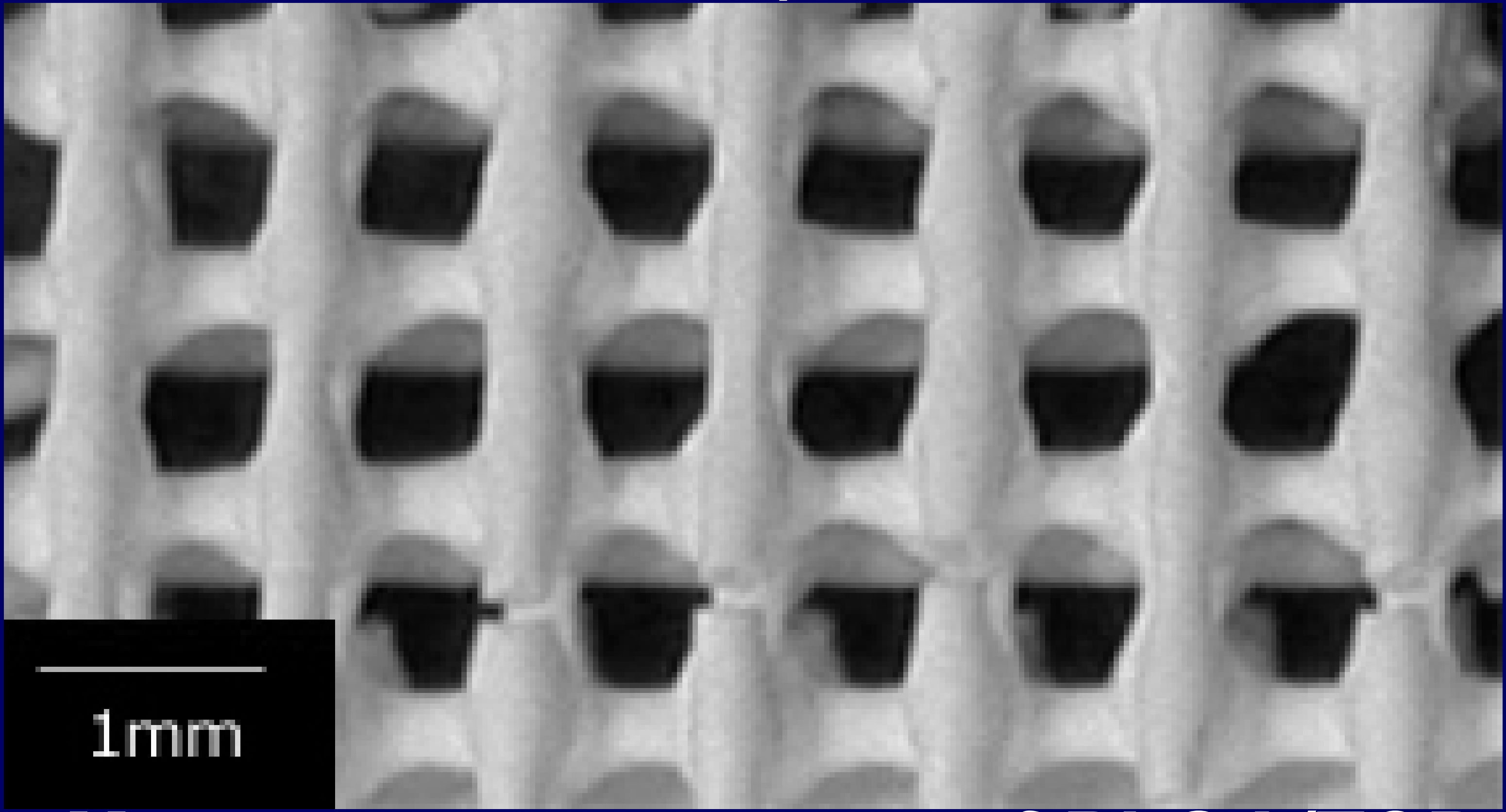
Macro pores structure of PLGA/TCP

From Solid-Liquid phase separation

Developed in CLRF, Tsinghua University

Scaffold poly (L-lactic acid)

Tricalcium Phosphate



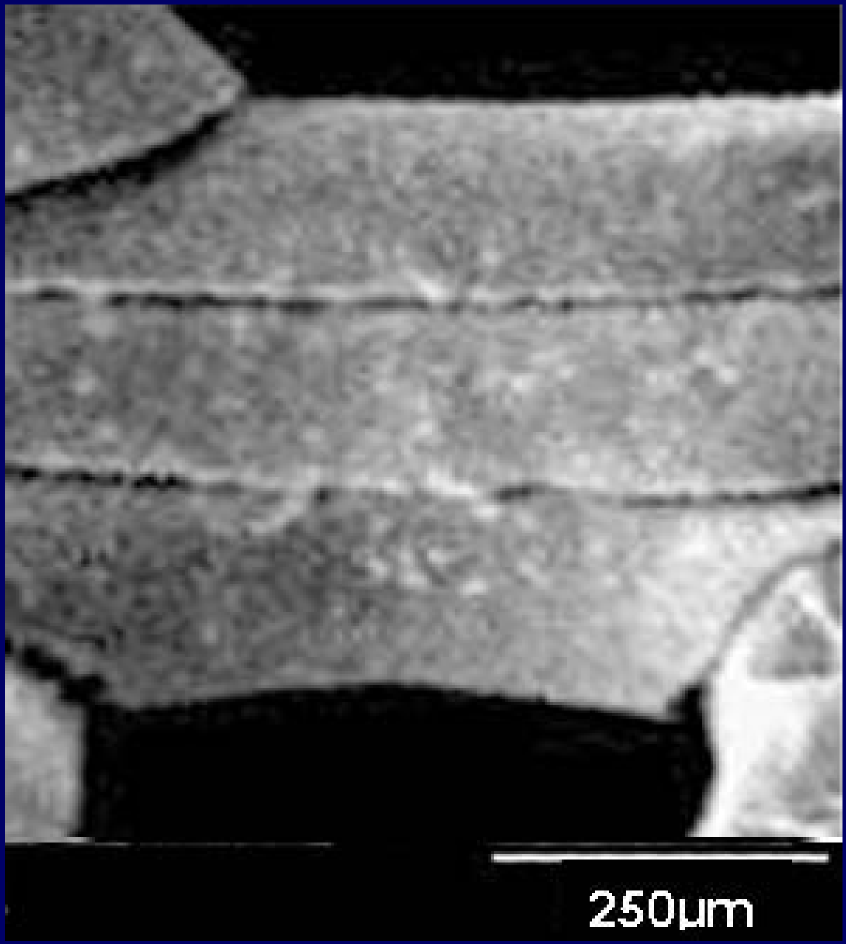
Macro pores structure of PLGA/TCP
From Liquid-Liquid phase separation

Developed in CLRF, Tsinghua University

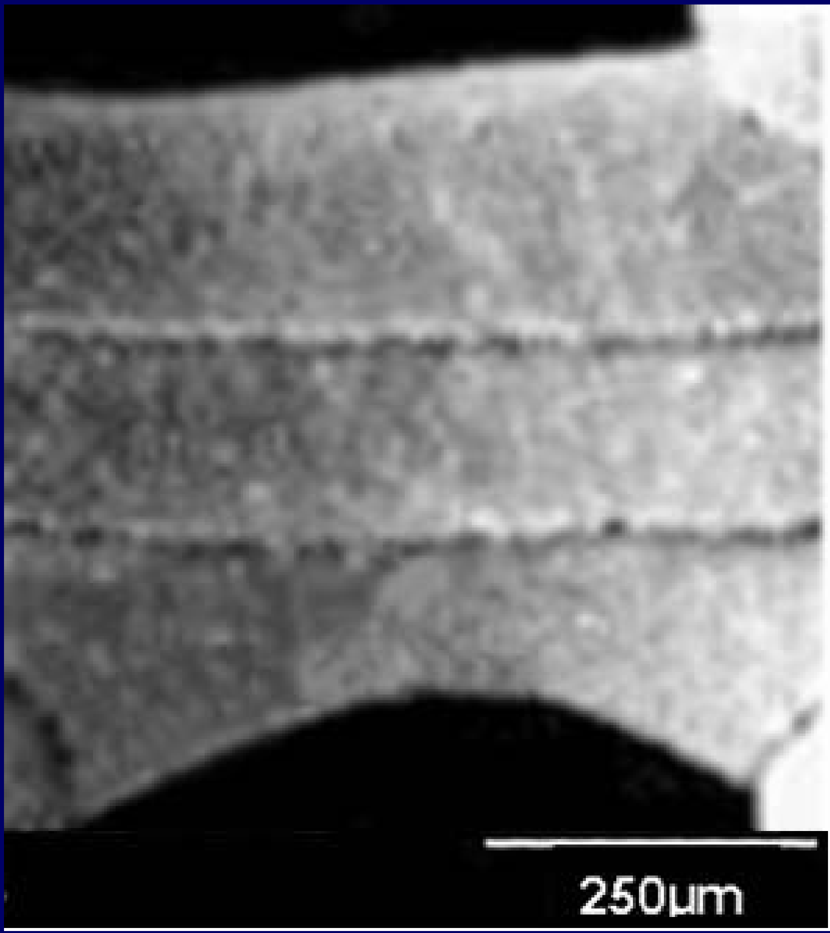
To ensure the desired porosity, it needs to adjust the temperatures of the nozzles and the environment.

Forming Processing

Forming Processing



(a) $T_N = 40℃$， $T_E = -40℃$

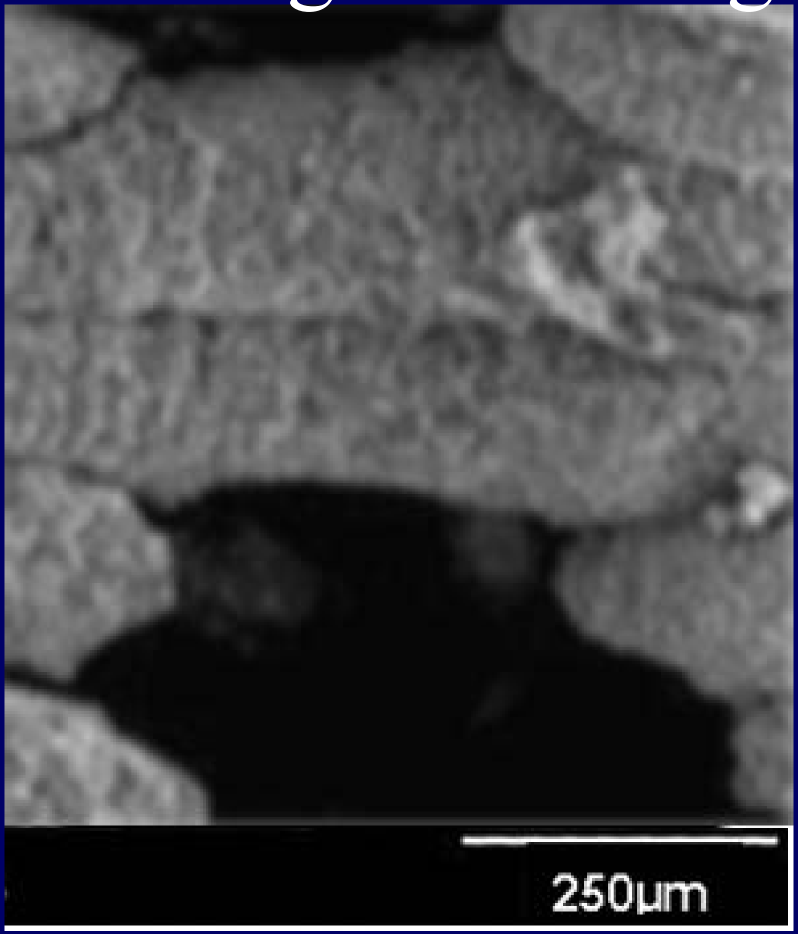


(b) $TN = 40℃$，
$TE = -35℃$

Forming Processing

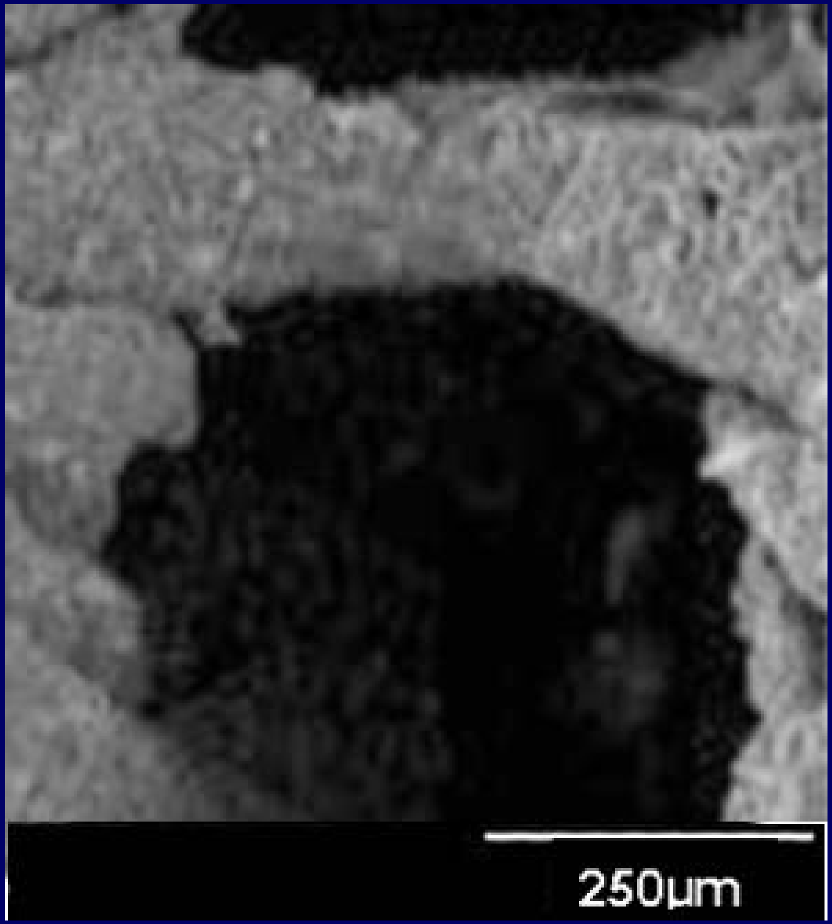
Forming Processing

(c) $T_N = 40℃$， $T_E = -30℃$



(d) $TN = 40℃$， $TE = -25℃$

Forming Processing

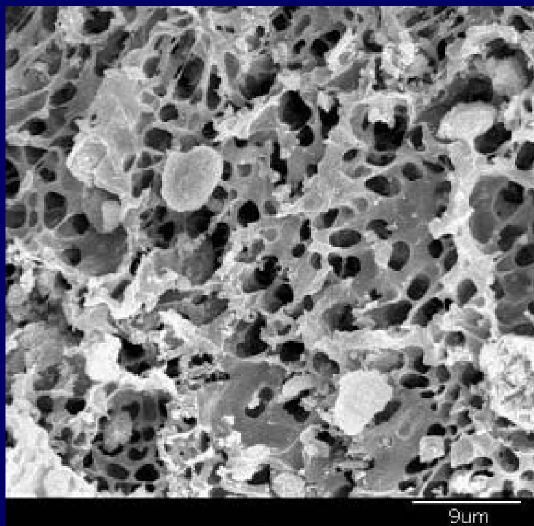


(e) $TN = 40$℃， $TE = -15$℃

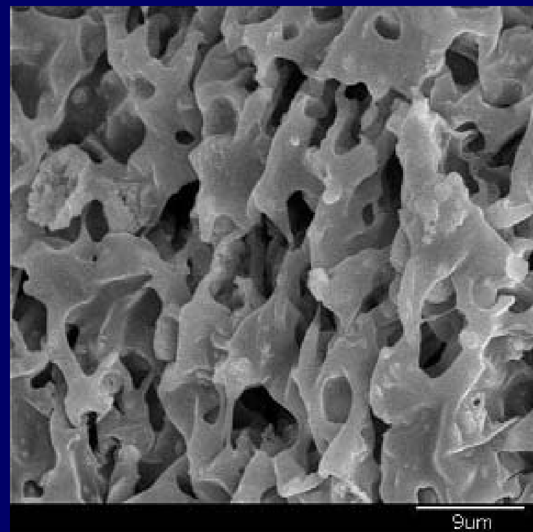
Forming Processing

(f) $TN = 40$℃， $TE = -10$℃

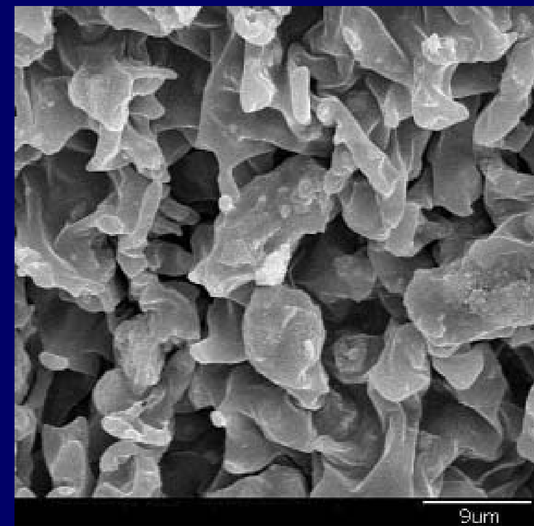
Material



(a) PLLA/TCP



(b) PDLLA/TCP



(c) PLGA/TCP

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BONE

Tissue Scaffolds

(Degradable)

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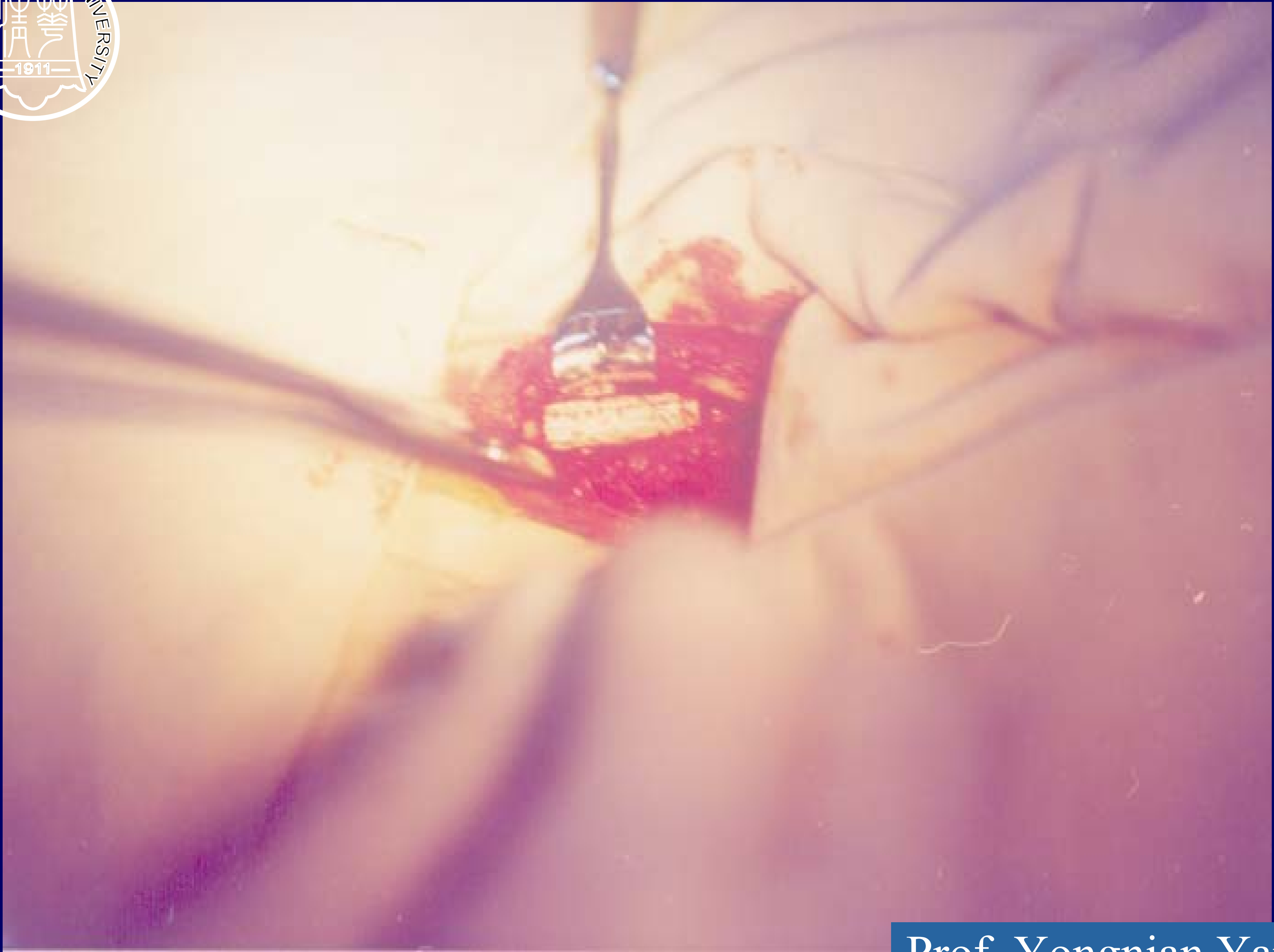

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Implant bone Tissue Scaffold

Dog

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No Scaffold

Dog

Prof. Yongnian Yan

Scaffold for Rehabilition of Microtia

(No degradable)

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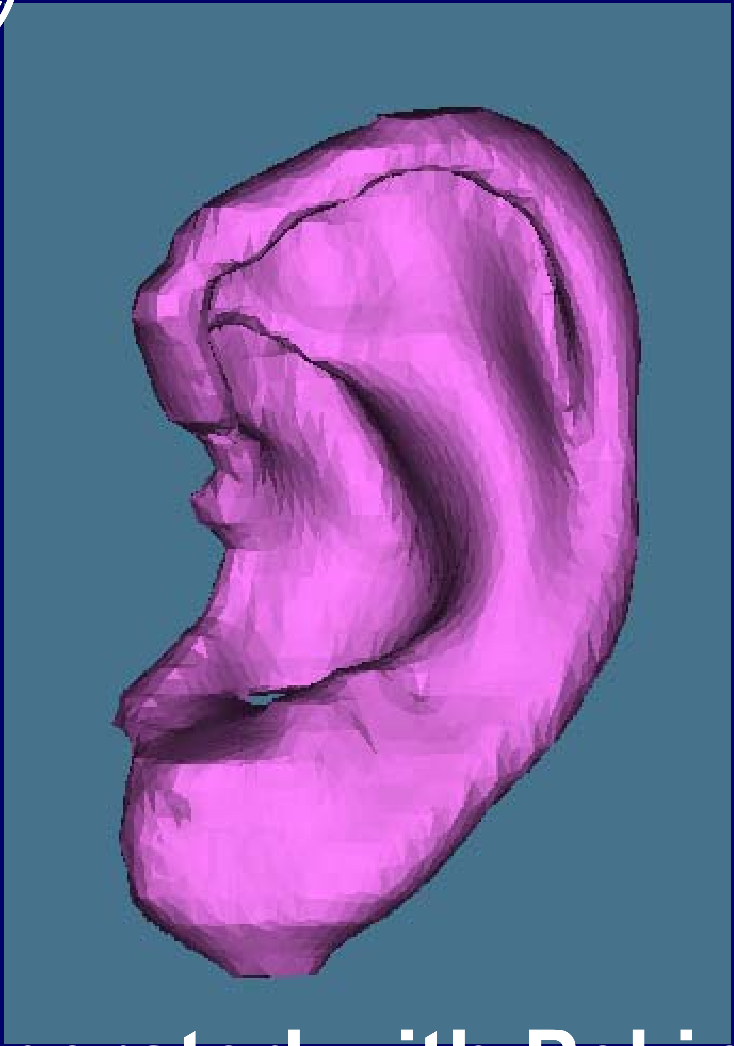
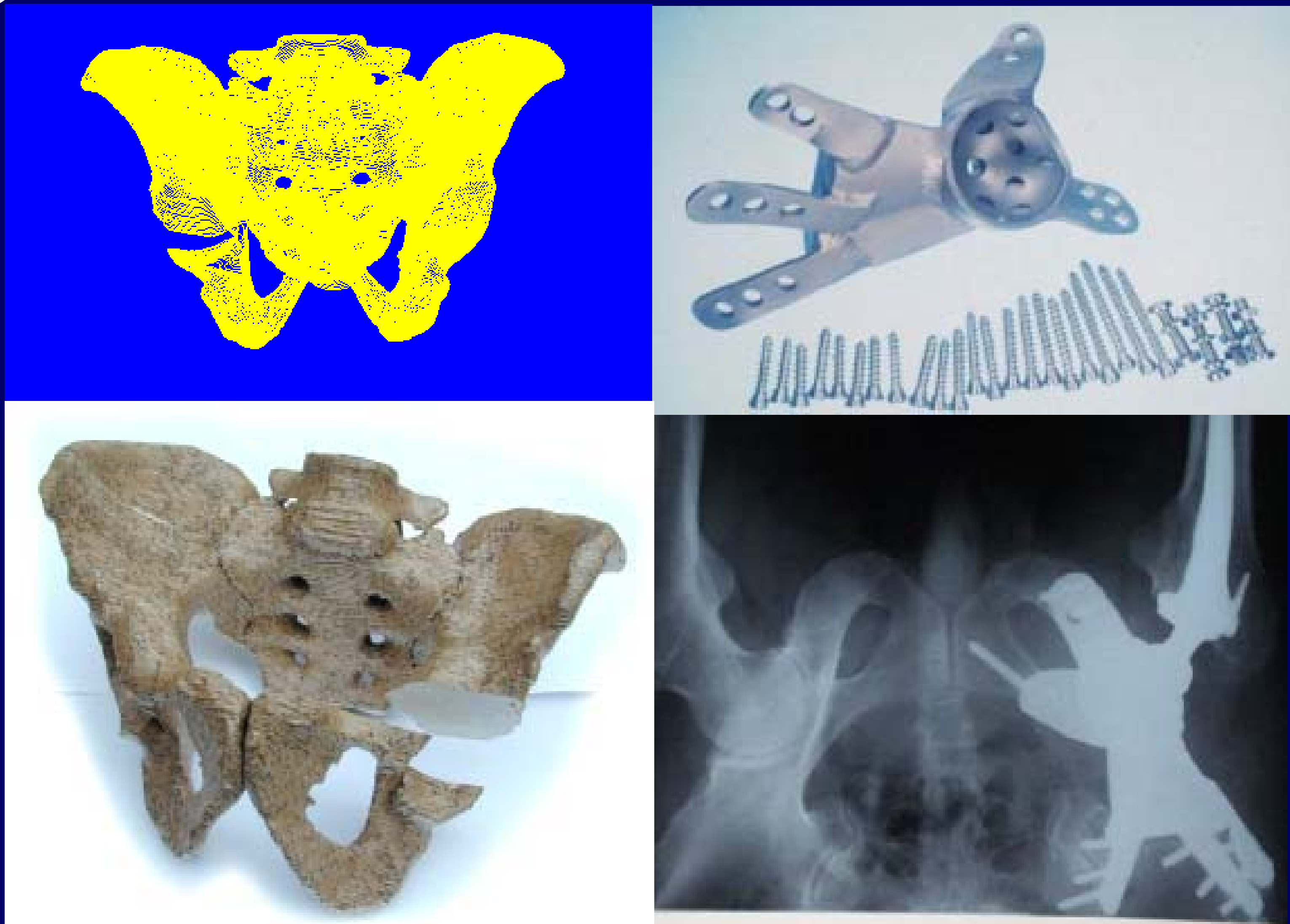
CAD Modle

Artificial ear



Cooperated with Peking Plastic Surgery Hospital

Rehabilition of Pelvis



Thanks